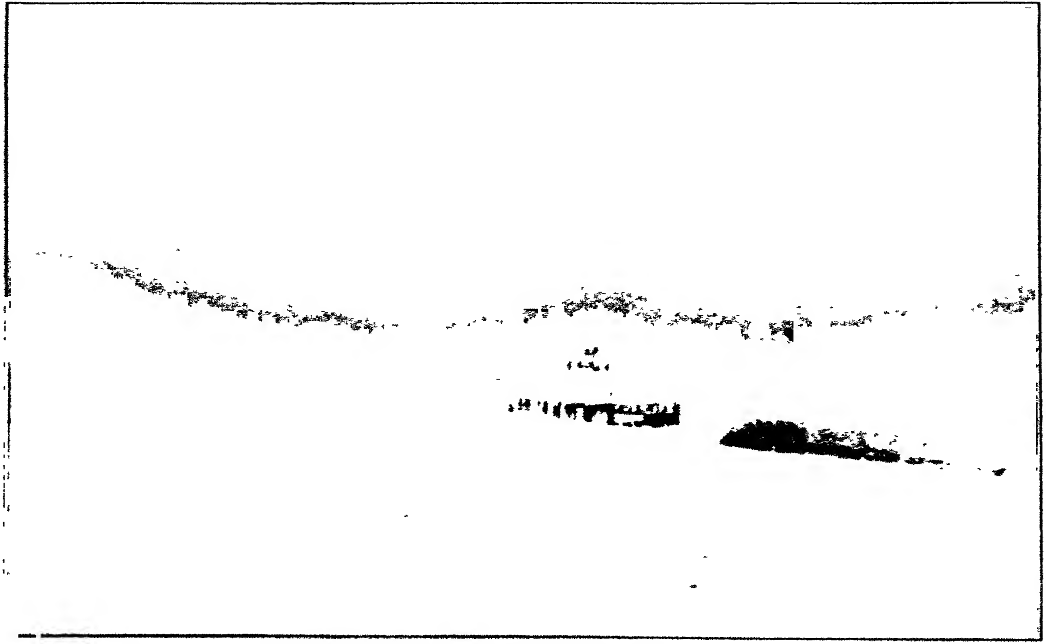

COAL-TOWING ON THE OHIO

REMAKING THE MISSISSIPPI

BY

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WITH ILLUSTRATIONS

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CHAPTER I

THE MISSISSIPPI SYSTEM

THE map of North America presents no more striking feature than the system of waterways which flow into or are allied with the Mississippi River. By the "allied" rivers I mean to include, not only those which parallel more or less definitely the lower reaches of the big stream, and are connected with it by inland courses, but also those more distinct waters which collect in the reservoir of the Lakes and flow eastward through the St. Lawrence, and those which drain down from the wheat-growing slopes of the Canadian Rockies to make the Saskatchewan, the Athabasca, and even the MacKenzie. For all these streams have their main courses in a great continental trough or depression, extending from the Gulf of Mexico to the Arctic, between the two continental ranges, the Rockies on the west,

the Appalachians on the east; and though they are to-day separate systems, they have recorded on their banks the history of a day when they all flowed together to the southward, and the prophecy of another day when they will all be linked into a unified, commercial system of carriers. The land which they drain is the fertile heart of the continent, constituting one of the most amazing regions in the world in the extent to which it possesses those qualities which make for habitability in the highest degree of comfort by white men and women. It includes the greatest wealth of the United States and of Canada: in the south the sugar and rice of the Gulf states, and adjacent to them some of the greatest cotton-fields in the world; north of them, again, the home of American corn; and still north of this a wheat-growing region which we shall never see equaled,—until, perhaps, Siberia comes into its own,—extending beyond the Arctic Circle and almost to the shore of the Polar Sea.

It is by no strained figure of speech that I have called this the heart of the continent, for it is the source and centre of our circulation, the

fount whence springs our life-blood, the never-ceasing engine, stagnation of which would mean death for the whole organism. It is therefore by an especially bountiful provision of nature that in and from this heart lead the most wonderful arteries for a national life which are provided for any people. From the MacKenzie, flowing to a frozen sea, through the Athabasca and the Saskatchewan, the Winnipeg and the Red River of the North and the Minnesota, through Rainy Lake and Pigeon River, the wheat-fields reach out not only to the cold shores of the Arctic, and of Hudson's Bay, but to the warm waters of the Lakes and the Mississippi. And these, in turn, from a union at the Chicago Divide, gathering together waters from Pennsylvania, New York, and the Carolinas on the east, from Montana and Wyoming on the west, from Texas and Oklahoma, and from Alabama and Tennessee, flow with them southward to the Gulf of Mexico or, from the other side of the Divide, make their way eastward through the St. Lawrence to the Atlantic. A parallel to that which the nations of Europe have striven a century to construct, a

continental system of internal waterways, America has here ready at hand, and so situated that on its banks must be produced and consumed the greater part of all that the nation produces from fields or factories or buys from other peoples.

When the settlement of this centre began, these rivers formed the natural channels by which people flocked in and by which their cargoes were handled. Later these people gave over the use of their steamboats to develop the faster and more certain railway. To-day these railways are congested and outgrown, and for bulk freights, at least, we are being driven back to the waterways. And when the centre is entirely populated, no thousands of miles of railway that can be built there, whether operated by steam or by electricity, by coal or by sunlight, will be capable of serving its trade. In that day these rivers will come into their own, and will prove as capable of absorbing the flood of commerce as of carrying off the torrents of rain and melting snow.

It is, however, with the Mississippi system proper, and only to a lesser extent with its allies, that we are here concerned; for it is the Missis-

sippi which lies to-day almost unused in the presence of the most rapidly developing and the most congested traffic of the continent. We are to examine here to what extent and by what means our engineers have learned how to make of these streams safe and reliable carriers, how far they have exercised that control, what it has cost, and what lies ahead of us in the ultimate conservation of this water resource.

We came to the use of these rivers in a period before the steam-engine was more than a useless toy, and before even John Fitch's boat had had its initial trip. We have forced them to serve us in advance of the developing of the science of river control by inventing and working out types of boats to use them in their primitive state. As our complex trade and civilization have developed until these types of boats no longer serve them, we have found ourselves unable to bring the rivers to a stage in which new types of boats satisfactory to commerce can operate economically. And this is for several reasons. While the river and the boats have been advancing we have been working out a new type of government and

conquering a new continent, and during much of that time we have been fighting and recovering from a great war. The duty or the ability of the nation to enter into such large works of public improvement has not been too clearly seen, and even in the year 1908, in which this is written, it is not yet possible to secure Congressional consent to an adjustment and distribution of the cost and the profit accruing from the development of the streams, or even to the development in its entirety of any single river. Unwilling, or unable through constitutional limitation, to take up the larger projects, or — and this has been very effective — too busy with our new lands and new businesses to give our attention to these things, we have been contented with piecemeal work, patching here and there, in an attempt to carry traffic from day to day. It is, therefore, my purpose in this volume, without attempting to account the blame for our serious defects, to show exactly what we have done and by what means we have done it, and to indicate as clearly as I can the condition toward which we are, or should be, aiming; remembering that the

entire subject of river development has been given a new direction in the past eight years by our increased knowledge of the possibilities of the electric transmission of power.

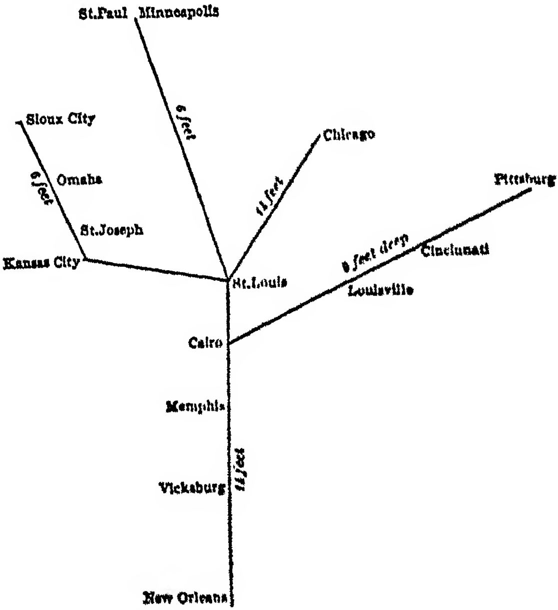
The Mississippi system consists of a veining of rivers spreading fan-wise, from a base on the shore of the Gulf of Mexico, northward, eastward, and westward to the most remote parts of the centre which lie within the United States. Into these rivers drain 1,244,000 square miles of land, two fifths of the territory of the Union exclusive of Alaska. They offer channels suitable for navigation from New York State to Montana, from Minnesota to the Gulf. No other river system in the world is so nicely situated with regard to the strategy of trade. Nowhere else is there another so populous and extensive region of absolutely free trade as lies within the tariff walls of the United States; nor is there another set of rivers which coincides so entirely with the final demands of both internal and external trade. The inevitable trend of all stable traffic movements is in two principal directions,—inward and outward between seaboard and interior, and

between northerly and southerly zones. The crops and manufactures of the interior must go to the seaboard and thence abroad to exchange for foreign goods, which return over the same routes; and the temperate zone and the tropics must ever exchange with one another those products in which each has a climatic monopoly. So we see the Mississippi reaching from the seaboard to the farthest corners of the interior, a natural channel to and from the coast; and at the same time with its main trunk exactly in the direction of interzone communication.

As for the purposes of traffic and of engineering development, so for our study we may divide the Mississippi into six principal streams or collections: the main river below St. Louis; the Ohio; the Chicago-Illinois route to the Lakes; the Upper Mississippi; the Missouri; and the minor tributaries. Of course, it is only by a free use of the term that we can include such majestic and important waters as the Tennessee, the Cumberland, the Arkansas, and the Red among the "minor tributaries." These six divisions comprise, all told, at least eighteen thousand miles of channel sus-

ceptible of development to a navigable stage, not including the allied waters to which they are connected. No accurate estimate of this amount has yet been made, but it is certain that more than sixteen thousand miles have actually been traversed by steamboats and have been taken in charge by the federal engineers. Leaving out of consideration for the time being those streams which we have assembled as "minors," and considering only the major channels which constitute what is often called the "trunk line system" of the Mississippi, and upon the immediate development of which the traffic of the centre is waiting, we may represent them graphically and simply by the diagram on page 10, which shows at the same time their general trend and the manner of channel which it is proposed to develop in them.

Had an engineer designed a gigantic system for carrying the products of the interior to the seaboard, he could have shaped no better plan than this for economy in construction and operation, for simplicity and directness. At the head of the Ohio we have Pittsburg, a region rather than a city, one of the greatest tonnage-producing cen-



tres in the world. Here originate immense shipments of pig and manufactured iron, steel in all shapes, glassware, and manufactured articles of many other kinds, which must be carried not only to the seaboard, but to the distributing centres at St. Louis and at the extremities of the other branches of the waterway. Here are the shipping points for the Pennsylvania and West Virginia coal mines, whence millions of tons each year must be carried down to New Orleans and the cities by

the way. Here, too, are great sugar refineries, in which the syrups of Louisiana are transformed, and factories and yards which require millions of feet of southern lumber, and must eventually import wood via New Orleans from Central America.

At the head of the Illinois route, where the rivers and the lakes unite, stands Chicago, the greatest railway centre in the world. Here, at the head of Lake Michigan, are gathered all those raw materials, sand, iron ore, coal, wood, fibre, pulp, which make possible the establishment of a large manufacturing centre. Here are gathered the corn and wheat of the West for forwarding or for transmutation into manifold by-products. Hence go countless tons of meat products, of iron and steel goods, of harvesters and reapers, of furniture, of clothing, of cereal foods, all requiring to be borne to the distant points of distribution and to the seaboard gateway of the nation. Here, too, are collected by great lake ships all the tribute of the cities about the Lakes, to be exchanged for southern goods or to be sent on down the rivers to the Gulf, and so abroad, and here the inland

western cargoes tranship for the farther reaches of the St. Lawrence and the Erie route.

At the head of the Upper Mississippi, where the great river plunges over fall after fall to generate eventually more than two hundred thousand electric horse-power, we have established the collecting and distributing centres of the North, St. Paul and Minneapolis. Here is already produced more than half the wheat flour of America. Hence go shiploads abroad, for which no better route will ever open than that by water straight down to New Orleans. Here the trade of the Northwest and the new Canada centres. And north of the two cities, along the Mississippi itself, are extensive deposits of iron ore, of a grade which will amply repay barging it down this natural channel to be smelted by the cheap and abundant coal and limestone of Illinois and Missouri.

Farther west still, the Missouri, plunging down over the Great Falls, with a force of five hundred thousand horse-power, and finding its way across the Bad Lands of North Dakota, where irrigation from it is rapidly working a miracle, comes by

Sioux City, Omaha, and Kansas City, the great depots in which the Northwest gathers in its yellow corn and its wheat, forwarding depots from which now everything goes by rail, but from which in time the Missouri will float them to the sea. Here, too, ends the overland haul of eastern import goods, and here they are broken up and distributed to all the hinterland. And at the junction of these streams, at the head of the main trunk line, stands St. Louis, a jobbing centre of the first importance, entrance to all the rich Arkansas and Missouri hinterland, a big manufacturing city and the controlling gateway for an immense east-and-west railway traffic.

These are the key points of interior commerce, and it is just in so far as it creates sufficient channels between them, safe, certain, and ample, that the Mississippi establishes itself as the burden-bearer of America.

In their natural condition these rivers are of course incapable of this feat. Sufficient for the needs of pioneers, their channels are obstructed by shifting bars and altered by moving banks; they are from time to time blocked by snags;

they are interrupted by periods of low water and by floods which obliterate landmarks. They suffer in the course of years from the depletion of the forests about their headwaters, and from the invasion of lumbermen who fill their courses with sunken logs. They require to be so altered that there shall be at all times a sufficient depth of water for profitable navigation, at no time too great a flood for safe traveling, and a channel absolutely free from snags, rocks, or bars. To provide such channels has been the task of the Corps of Engineers of the United States Army. Aided by irregular and insufficient appropriations, working necessarily without any definite system having been adopted, and handicapped at every turn by those political obstacles which necessarily beset government employees in our country, they have toiled steadily forward on individual streams until they have solved in detail all of the many problems which are concerned in our task; and, while bringing fairly good channels to many parts of streams, have shown the way to go at the whole effectively. This "going at the whole" has in turn been definitely entered upon, and we are in dis-

tant view of the day when the desired end will be attained.

It is not my purpose to discuss here the manner in which the mode of expending money on river improvements has grown, or in detail the present condition of this expenditure. Briefly, our earliest method was for Congress to direct the person under whom each appropriation should be expended, who was usually a treasury officer, and most commonly the nearest collector of revenue. Later it was necessary to indicate the Secretary of War in many cases, as he alone had under his command engineers capable of making surveys of rivers and harbors. Later still, as the River and Harbor Bill became an established thing, and the question of government policy on river improvement was definitely decided, this grew into an established procedure. At the close of the Civil War it became one of the chief fields of activity of the army engineers. Although no school of practical instruction except the work itself has ever been provided for them, they have as a body continued to advance in their new science, and have been organized into a regular staff, through the chan-

nels of which with military precision and red tape go surveys, recommendations, appropriations, and other reports from the captain-engineer in charge, through the general-engineer at Washington to the Secretary of War, the Rivers and Harbors committees, and Congress itself.

In the early days of river improvement much work was done by the several states; and even to-day work of the most valuable character is being thus accomplished. Many other tasks, as the damming and locking of certain coal-region rivers, have been done under state charter by private companies entitled to charge tolls. Thus Ohio developed the Muskingum; Kentucky the Green, Barren, and other streams; Arkansas and Louisiana appropriated money for the Jefferson Bayou, the Washita, the Black, and many other channels which were in the early days their only roads. All private charters are, however, now extinct, and all navigable waters are toll-free.

Up to the end of 1907 the development of navigation in the rivers of the country, under the general name of "improvement," had been considered as a thing by itself without regard to what

other uses of water or of land may have required different treatment.

At that time, however, there was appointed an Inland Waterway Commission by President Roosevelt, the creation of which marked the breaking away from tradition and the establishment of a new policy. Under this new policy, which is one of the utmost conservation of all our national resources, the waters are to be developed for all purposes simultaneously. Reservoiring to prevent floods, to develop and steady water powers and to maintain navigation, will be done more extensively. The planting of forests to reserve water naturally will be more largely indulged in. Tree planting to prevent soil wash will become a feature, and the use of the rivers for irrigation and for power will be made to go far toward paying for the improvement of the same streams for navigation.

All told, the national government has expended on the Mississippi and its branches between two hundred and two hundred and fifty million dollars. Much of this sum has been spent in learning. Much of it has been wasted. Much of it remains,

however, in permanently improved channels, and in public works ample for their task for a century.

As a result of the expenditure, there are now in the principal branches of the trunk system the following channels: in the lower Mississippi, from the mouth to Red River (300 miles), ample water for the largest ocean steamship; from Red River to Cairo, 9 feet at all stages and usually 10 feet, in a channel 250 feet wide; from Cairo to St. Louis, an uncertain channel nominally 8 feet, but sometimes reduced to 5 feet; from there to La Salle, 100 miles from Chicago, 6 feet in the Mississippi and 7 in the Illinois; in the Upper Mississippi above the Illinois, 4½ feet to St. Paul, with usually 5 feet, and an incomplete 5-foot lock system to Minneapolis; in the Missouri, an uncertain and ill-kept channel practically abandoned by the engineers and by traders, with usually 3 or 4 feet at summer stages as far as Kansas City; and in the Ohio, an uncertain river perhaps 20 inches to 3 feet at lowest water over the worst bars, with a heavy commerce in flood time, and with its upper reaches being slowly improved to 9 feet of depth by a system of locks and collapsible dams.

CHAPTER II

THE HYDROLOGY OF THE SYSTEM

A PROPER understanding of the problems and methods of the development of navigability in a river and the control of its waters and their channel, necessarily depends upon these things,—a knowledge of the hydrology of the stream and its tributaries, of the land on which the rain supply falls, and of the bed in which it finally locates itself. On all of these matters our engineers have made long and detailed reports of the several parts; though, owing to the divided nature of our public works among cabinet departments, there is no official and complete report upon either the hydrology or the character of the beds and the navigable length of the streams. One finds river measurements in the War Department, supplied from the reports of Major Humphreys and Lieutenant Abbot, which do not agree with those of the Census Bureau, nor do either of these agree with the

figures of the Geologic Survey. Nor does the latter always agree with itself. For accurate figures on stream length, it is often necessary to go to a certain very complete report on our streams prepared by M. Vetillart for the Public Works Department of the French government. Thus we find in the Census and in the Irrigation papers two reports on the drainage area of the Missouri, one of 527,000 square miles, the other of 492,000. The navigable length of the river is given by the Treasury Department as 3127 miles, the total length of the same river by the Missouri River Commission as 2503 miles, and the navigable length as 2378 miles.

Such errors are not confined to the Missouri. It is not my purpose, however, to comment on them more than to point out some of the difficulties which still stand in the way of a complete and accurate account of these rivers. Estimates of the average flow of the Ohio vary as much as twenty-five per cent.

When the government figures on which we must base our own decisions vary so widely, it is difficult to present a hydrological table for which

respect can be expected. Nevertheless, having compared the figures prepared by Mr. Greenleaf with those of the Geologic Survey and whatever others could be obtained, I believe the following table, which follows pretty closely the Census estimate in most points, gives a view of the creation of these rivers that will not far mislead. At

River.	A	B	C	D	E	F	G	H	I	J
Upper Mississippi .	173,000[1]	34 7	27	.688	2.56	.144	25	118[2]	550	3,720
Missouri	527,000[3]	10.6	12	.178	1.14	.047	25	94[4]	600	3,500
Ohio	214,000[5]	43	30	.740	5.61	.163	35	158	1200	5,000
Arkansas . . .	161,000[6]	28.3	16	.300	1.55	.024	4	48	250	1,513
White	28,000[6]	42		.750	4.29	.161	4.5	20	120	630
Red	97,000[7]	38.3	18	.515	1.86	.036	3.5	50	180	1,576
Minnesota . . .	16,027	28	23	.474	3.75	.031				240
Wisconsin . . .	12,280	35	36	.928						350
Illinois	29,013	37	24	.7						
St. Croix	7,576	30	37	.825						
St. Francis . . .	7,989	41.3	70	2.130	4.5	.438	3.5	17	36	500
Yazoo	12,794	53.3	70	2.749	6.15	.384	5	35	80	1,100
Entire Mississippi . .	1,259,000[8]			.505			175	664	1800	20,144

A, area of drainage in square miles.
B, rainfall in inches per year.
C, per cent of run-off, or rain reaching river.
D, average flow in second-feet for each square mile of drainage.
E, average high-water flow, second-feet per square mile.
F, average low-water flow in second-feet per square mile.
G, minimum discharge in thousands of cubic feet per second.
H, average discharge in thousands of cubic feet per second.
I, maximum discharge in thousands of cubic feet per second.
J, total annual discharge, normal, in thousand-millions of cubic feet (that is, three sets of ciphers omitted).

[1] Humphreys and Abbot, 169,000. ; Census, 170,035.
[2] Geologic Survey and H. and A., 105.
[3] Geologic Survey, 492,000 ; H. and A., 518,000.
[4] Geologic Survey and H. and A., 120.
[5] Census, 207,000.
[6] Census, together, 184,742.
[7] Census, 92,721.
[8] H. and A., 1,244,000.

any rate, it establishes their relations among themselves with considerable accuracy.

From these figures it is at once apparent that the tributaries of the main stream vary as widely in character as in geographical distribution, from the extreme of the Missouri, with but twelve per cent of the water which falls on its enormous watershed reaching the river, to the Yazoo, which brings to the Mississippi seventy per cent of the torrential rains which flood its valley. Were the conditions of rainfall and run-off which prevail in the Yazoo maintained over the Missouri watershed, that river would have an average discharge exceeding the maximum floods of the Ohio, instead of little more than half the average of that stream as now, and if maintained over the whole valley, would give the Mississippi an average discharge of about 3,600,000 second-feet.

Shut off from the eastern and western seacoasts by ranges of mountains, the Mississippi Valley draws most of its moisture from the Gulf of Mexico. As is well known to those who follow the daily weather maps, cyclonic storms move inland from that body, up the Mississippi, and pass

over either by way of the Great Lakes and the St. Lawrence, or by way of the Upper Ohio and New York. These storms bring moist winds and heavy masses of clouds, from which the rain descends heavily as they move inland, causing the rainfall at the lower part of the main Mississippi to be many times heavier than that above; the record rainfall at New Orleans being more than nine inches in a single day and at Vicksburg nearly eleven inches in thirty-six hours. This progress of the main storms up the valley is the cause of the high rainfall and steady discharge of the Yazoo and the St. Francis, which lie directly in the course of the moisture streams, and draw their waters partially from broad, low, forested areas and partly from the front ridges of hills which border the major bed of the river.

The first obstacles in the path of the storms are the Ozark Mountains, which draw down a heavy flow of moisture. This goes in part into the White River of Arkansas, giving it the high run-off of three quarters of a cubic foot a second from each square mile of its watershed, and part to the St. Francis and the Arkansas, partially

making up to the latter for the dryness of its upper watershed.

Those storms which move north to the eastward of the Mississippi encounter the mountains and high hills of central and eastern Tennessee, where they create the Tennessee and the Cumberland, and passing beyond are still further denuded of water by the higher peaks of the headwaters of the Ohio, to which stream they give the copious abundance of an average of forty-three inches of annual rainfall. Those which have come up the valley and passed the Ozarks encounter near the Great Lakes cooler currents from the northwest, which cause further precipitation and provide for the upper central valley a fairly steady though not excessive supply of moisture. But the great region west of the Ozarks, comprising the watersheds of the Red, the Arkansas, and the Missouri, receives but a small part of the moisture-laden air from the Gulf, and from that but a sparse precipitation.

Still another factor enters into the problem of the rivers, in the distribution of this water supply through the year. It so happens that the Ohio,

with a copious rainfall, receives the greatest part of this in January and February, with some in December and March. At that time in the year the hillsides are frozen and absorb little, the sun is obscured and the temperature low, so that there is slight evaporation. Consequently the bulk of the water finds its way quickly into the streams, which are swollen in those months by sudden freshets of enormous height, the river sometimes rising sixty-five feet above low water at Cincinnati. These floods do not come every year, but in occasional years when the precipitation in the winter months becomes abnormal. It has at times exceeded normal in those months by seventy-five per cent. As the spring advances even equal rains upon the Ohio produce less effect upon the stream and its tributaries, the Cumberland and Tennessee never sending down a late flood, and the Ohio itself never but once having produced an August freshet. Absorption and evaporation take care of the rainfall until, left to its natural conditions, the Ohio becomes but a fortieth of its high-water self. Its lowest water is about the end of October, and there is often a small rise in November.

A different condition obtains on the Upper Mississippi. This river springs from a series of lakes in a heavily wooded region, from which there is an approximately uniform flow throughout the year. After a slight April rise from early rain and melting snow, the main rise comes in the late spring, and continues into June, though sometimes passing its climax much earlier. Many of its tributaries, such as the Wisconsin, preserve a similar character, the latter rising to a total discharge of .928 cubic foot per square mile—a sharp contrast to the Minnesota, a prairie stream sometimes considered the original prolongation of the Mississippi, which, with a larger watershed, produces but half the flow. The combination of all these streams is sufficient to send high water down the Upper Mississippi usually in May, but frequently as early as March or as late as June. Its high-water flow alone, however, is not sufficient to produce a freshet in the lower river.

The Missouri, with its enormous watershed, receives but a scanty rainfall during the months when the Ohio and Mississippi are at their maximum. Although swelling a little in April, not

until May does its water come in semi-abundance, May and June each frequently having as much as all the preceding three months. When the heavy rains do come they find the soil parched, and sink in and are lost, or, before reaching rivers, are dried up by the hot sun. Melting snows in the mountains produce some aid throughout the summer, especially on the main river above Great Falls and on the Upper Platte; but the rise which moves slowly down the Missouri in May and June, though drawn from more than twice the area, attains at most to but half the magnitude of the Ohio freshets. If it comes late for the Upper Mississippi it passes harmlessly out to sea, but in those exceptional years when the Upper Mississippi is delayed or a late second rise takes place therein, and the two become synchronous, there is witnessed one of those famous June floods which have in earlier and unleveed days spelled disaster to planters along the lower river. The river falls in September, but reaches its lowest stage in November, as the ground freezes.

Sometimes these conditions are widely altered. Thus the year 1903 saw all traditions upset, when

a mighty freshet from the Ohio in February found the lower tributaries above the Arkansas in flood, and made new records in the valley, to be followed three months later by high water proceeding from sudden and extreme rainfall on both the Upper Mississippi and the Lower Missouri, which sent those two rivers into the still high stream below Cairo with large resultant damage. But that is unusual. The season on the united river comprises in most years one, or even two very sudden high waters from the Ohio in February or March, becoming dangerous only in exceptional years and by virtue of other influences; a period of easier water following them, and then a gradual swelling from the upper river through May, added to by lower streams and reaching its maximum as the tardy Missouri pours forth its tawny volume in time to make good the deficiency of the decreasing central rivers. Reaching its maximum toward late June, this then subsides. The Ohio is shrunken as quickly as it rose, the Cumberland and the Tennessee are down, the Arkansas has fallen, and the Red as well, and by the middle or end of August the whole lower sys-

tem has usually dropped to that depressed condition known in the valley as "summer water," which is only alleviated by the Missouri, and which in some years may not fall below six or seven feet on any gauge, and again may show markings close to or below zero of the scale. This low water is of varying duration. Sometimes it lasts but a few weeks. Sometimes, as in 1901, it holds into December. Usually it is broken up by the fall rains on the Upper Mississippi and a gradual improvement on the Ohio, marked frequently in November and December by sharp waves from the latter as the first winter snows are melted by belated rains.

The effects of these floods and low waters on the several streams are as varied as are the streams themselves. The Ohio comes down from an aged and well-established region, in which its channel has been worn to the rock. It comes clear of sediment except when the Allegheny or some similar tributary is pouring a deluge into it, and even then has but a small amount compared with some of the others. It is essentially a rock-ribbed, clear-water stream. The Upper Mississippi also

comes down to the Chain of Rocks above St. Louis almost guiltless of the stains of erosion, and traveling to a considerable extent in a bed permanently shaped by a rocky contour. Not so the Missouri. That stream, which has rightly earned the nickname of "Big Muddy," gains that soubriquet in the long middle reach between the point where it leaps forth from the confining fastnesses of the Rocky Mountains and the point a thousand miles farther down where it enters a land of fairly steady rainfall and general conditions. In that middle stretch it flows through the well-known "Bad Lands" of western Dakota and Montana. There every rain of however small proportions has its erosive effect, and when the May and June downpour comes upon the dusty ground it runs with fast accumulating burden of silt to the Missouri. So fast does this accumulate and so great is the burden—which, indeed, shapes the whole control problem of the Missouri and Lower Mississippi—that the suspended matter at times rises to one thirty-first by weight of the whole moving stream. This silt must be carried to the sea, and the effect of its carriage, and the gen-

eral works which aid to keep it on its way, will be described in later chapters.

As the basis for all leveling must be a proper bench-mark, so on the Mississippi the corps of engineers have established certain optional marks at convenient points on the main river and all its tributaries, and from these levels as "zero" have at many points erected gauges by which to read and record the height and movement of the river locally, and to establish the proper grading of improvement works. These zero marks are at each point supposed to represent "low water" of some character, generally in a conveniently chosen year or on an average of several years. They are referred for final definition by way of "Cairo datum" or "Memphis datum" to the mean level of the Gulf of Mexico at Biloxi, and beyond that they have no other meaning that is other than relative. The "height" of the river at any point or time as referred to the gauge means not the depth, nor the navigable depth, nor the actual height of the existing rise, but the present level of the surface above the zero mark on the local gauge. Thus, at St. Louis "normal"

low water is about four feet above zero on the gauge. At Memphis, in December, 1901, the river stood two tenths of a foot below zero. Yet at the time there was ample water over all bars even in the "Plum Point region" for navigation as there carried on, and in the river in front of the gauge the water was more than one hundred feet deep.

These gauge readings, however, serve a very good purpose aside from the aid they give to the navigator. Current velocities at given stages having been determined by experiment, the officers of the Weather Bureau, who have this department of river control in charge, are able to determine the speed with which a flood is moving off. Knowing the amount of rain which has fallen on a watershed, and the condition of that watershed with regard to its ability to retain moisture at that time, they are able to determine with much exactness the amount of water which will enter a stream, the speed with which it will come, and the height to which the rivers below will rise. This information they send out in daily bulletins in time of danger to cities and villages ahead

of the flood, and furnish also to navigators; so that those who are to be affected by the rise of the waters will have accurate and timely warning.

There is reason to believe that with the cutting away of forests, the progress of irrigation, and the cultivation of the soil, the hydrology of some of the branches of the Mississippi is slowly changing. How large and how influential these changes are can be determined only by close study and must depend upon an accurate survey. Meanwhile many methods have been adopted by which the régime may be artificially modified, as by storing flood waters, by planting trees so that a forest cover may retain the rainfall, and by preparing the earth to absorb the rain. These methods will be considered more at length in the chapters following.

CHAPTER III

CONTROLLING THE MAJOR BED

THE problem of river control for the purposes of navigation and for the prevention of floods is but a part of the general problem of the conservation of a river; though it is but recently that this larger problem has come into recognition. The proper conservation of the water falling upon any given drainage shed requires that from the time it falls until it is merged in the sea it be so conducted as to force it to yield its maximum advantage for agriculture and for forestry, the largest possible percentage of the power which is developed by its descent from the land on which it lights to sea level, and the largest good to navigation; while at the same time carrying away a minimum of soil and doing the least damage to the region through which it flows. This requires that about the sources of principal streams considerable forest areas be maintained, to prevent erosion, to retain silt, and to hold in

check, beneath the forest cover, a considerable amount of the rainfall both as an ameliorating effect upon climate and for the purpose of providing a fund for supplying the river in dry spells. It requires also the establishment of reservoirs about the headwaters of principal and even of the smaller streams, by the enlargement of lakes and ponds by dams, and the storage of water in ravines and gorges by the same means, to hold back excessive rainfall and prevent floods in the valley, while at the same time providing a better low-water flow. It requires the erection of dams at every quick water along the course, for a double purpose: first, for the benefit of navigation, providing deep water over the shoals of the rapids; and second, to create a definite "head" of water at which the power in the fall of the stream can be developed. This power, which in many rivers would be very small in low-water seasons, is multiplied in value by the establishment of the forests and reservoirs, which make the flow uniform; and if properly handled for the public gain or properly taxed, will pay back in return the cost of making the improvements.

Farther down, the development of the stream requires that flood waters which are not impounded shall be retained within banks, and not allowed to overflow adjacent lands; and that the low-water flow shall be so restricted and in so permanently established a channel as always to provide a safe way for navigation.

For the latter purposes, that is, for preventing floods and providing a channel in the lower courses, several measures are undertaken: first, the erection of false upper banks or levees along the river's course to restrain floods; second, the retention of water in local artificial reservoirs along the stream itself, in a series of pools separated by dams and connected by locks; third, the establishment of permanent courses by the artificial hardening of the river bank to prevent erosion; fourth, by removing foreign substances and preventing them from entering the stream; fifth, by so contracting the low-water channel by dikes, dams, and other means as to force the water to flow in a narrower and therefore deeper bed; sixth, the removal of natural obstructions, such as bars, rock ledges, etc., by dredging or blasting. All these

means in various combinations are used on the several arms of the Mississippi system, the use of each being dictated by the nature of the river and of the bed in which it flows,—by the hydrology of the stream and the character of the bottom.

Every river has, in fact, in its natural condition, two beds, the major and the minor. The major bed of a stream is the territory it occupies in time of flood. When it has risen "out of its banks" and has begun to spread over adjacent lands and swamps, it quickly fills and flows in its major bed. The minor bed is the bed between the banks, in which it flows at all ordinary stages. On the Mississippi River below Cairo these banks are from twenty to forty feet above ordinary low water,—zero of the gauge,—and are separated a distance of from one half to three miles. In between them, in a still more constricted channel, the river flows at extreme low water. When big floods come, sometimes attaining a height of fifty or even fifty-five feet at Cairo above extreme low water, it flows over even the higher of these alluvial banks, and filling the swamps spreads back to the distant hills, often before the levees were

built attaining a width of forty miles. This overflow strip, a region of fine alluvial land, eight hundred miles long and forty wide, from the Chickasaw Bluffs on the east to Crowley's Ridge on the west, is the major bed of the Lower Mississippi.

Not only the preservation of this immense area, twenty-nine thousand square miles, but the needs of navigation and of health require that the river should be retained as nearly as possible in the same bed at high water as it occupies at lower stages; that is, though it rises many feet above its banks, it should be so shaped that it would still flow in exactly the same direction at all points, following the same bends and crossings. Though this state has not yet been reached, and the river is still allowed to "cut corners" at flood, it has at least been approximated by the construction of artificial banks upon the natural ones, sometimes to a height of thirty feet. These artificial banks, of which there are now about fourteen hundred miles along the lower river, are in fact nothing but earthen dams, more or less parallel with the course of the stream, against which it stands at high water, often to the very top. As

this is the example of levee protection not only upon the Mississippi but in the world, it will serve here to illustrate the whole subject of major bed development.

In order to understand this, however, it is necessary to have a clear view of the river itself and the region through which it flows. As we have seen in the chapter on hydrology, the Mississippi is made up of three great divisions,—the Ohio, the Missouri, and the Upper Mississippi. To these there was anciently added a fourth, the greatest of them all, which came down from the Great Lakes at Chicago by way of what is now the Illinois River. Of these three divisions, the greatest in volume is the Ohio. The other two are about equal. The Ohio comes down from a steep, mountain country, in a permanent rock-compelled bed, with very few places in which it can make a decided shift in its location. It is naturally subject to sharp high floods, and overflows considerable areas in its own valley. The Missouri comes down from the western mountains over and through a vast plain where any sudden waves are gradually lengthened out, much is lost by evaporation and little addition is

received from tributaries. It flows between soft banks, which are in turn shaped in the last resort by high bluffs, located in general from a mile to two miles apart. Similar bluffs, of great height and beauty, border the Upper Mississippi. But this stream, which once had a far greater volume than it has in modern times, comes from a country vastly different from that which gives rise to either of the others. The northern part of Minnesota and Wisconsin is a region of level plateaus, covered with heavy woods, and richly-grassed prairies. Millions of acres are covered with lakes and swamps in which are stored the spring rains and melting snows, to flow out with fairly steady discharge during the summer months. Though heavy rains send a spring rise and occasionally high water later in the year down the upper river, it nowhere attains heights such as do the freshets of the Ohio.

Not far from the confluence of the Mississippi and the Ohio, and about one hundred and eighty miles downstream from the mouth of the Missouri, the Mississippi breaks through a spur of the Ozark Mountains and enters a region entirely different from that occupied by either of the

three upper streams. Between Cape Girardeau and the city of Commerce, Missouri, the river seems trapped in a cul-de-sac, the bordering cliffs crossing directly over its course. It twists and turns tortuously, and, in a stretch of channel remarkable for its rock reefs and obstructions, breaks its way out into the alluvial bottoms of the lower valley. Whether, as some hold, this was the ancient mouth of the river, and all the bottoms from this point to the Gulf — eight hundred miles — have been created out of sediment brought down in millions of years from the hill country above; whether the land from here down has been made dry by the subsidence of the sea or the upheaval of the bottom; or whether the ancient river flowed between banks all the way down to Baton Rouge and has merely filled up its ancient bed with silt as it has diminished in size, — for all these theories have been put forward and defended, — it is certain that from here down the river flows in a land of its own creation, in which it still destroys and builds up, makes bars, shifts its channel, and cuts in new directions, not as freely as in its pristine condi-

tion, but far more freely than it will be allowed to do when the engineers have completed their work.

From Commerce down, the bordering hills are about forty miles apart, constituting, as I have said, the major bed of the river. Through this the river itself, in its minor bed, winds an irregular course. From the west side, at Commerce, it crosses by a long and crooked diagonal to strike the easterly bluffs at Columbus, Kentucky. Following them with more or less regularity as far as Memphis, it then moves in an opposite diagonal back to the west side at Helena, Arkansas. It thus has left, between itself and Crowley's Ridge, an irregular tract, pointed at both ends, forty miles wide in the middle, and containing about six thousand square miles. This region is known generally as the St. Francis basin. In it the land is composed of layers of earthy mould, sand, and silt from the river. At the riverside, where there have been no recent changes, it stands about forty feet high above low water. From this point it slopes downward and backward about seven feet in the first mile, and after

that a foot to the mile, to the bluffs, or rather to the St. Francis River, which, with some irregularity, follows the trend of the bluffs. The drainage of the swamp is through this back river. The greater elevation of the land at the Mississippi side is due to the fact that its waters are heavily burdened with the suspended earth of which these bottoms are built. As they spill over in flood they lose speed, and also their ability to carry silt. The greatest burden is deposited at once, and the smaller amount farther back. The stream at the back has a very gentle slope and a sluggish current; and as the Mississippi has a greater slope, the St. Francis, which in its upper reaches is perhaps fifteen to eighteen feet below the larger stream, flows into it at Helena.

From Helena the Mississippi turns easterly again, and, leaving the westerly hills, takes another long, diagonal course to the east side, which it strikes at Vicksburg. It then follows that side with more or less regularity to Baton Rouge, and there, leaving the high ground for the last time, passes down in mid valley through its delta to the Gulf, passing no more land which is above its

own flood level. Between Memphis and Vicksburg, on the easterly side, it leaves a second tract slightly larger than the St. Francis basin, but almost identical in character, known as the Yazoo Delta, because of the stream which drains it along its bluffs. Below Helena on the west, and above the Arkansas, it leaves another, which is called the White River swamp, and below that on the same side the Tensas, and below that the Atchafalaya. The Plaquemines region lies along both sides toward the mouth of the river.

These great swamps or bottoms of the Mississippi — and it must be remembered that in calling them "swamps" I am referring to their natural condition and not to their present estate — have had an influence extremely important upon the régime and the navigability of this section of the river.

There comes to the Mississippi, chiefly from the Missouri, a great burden of suspended earthy matter, usually very finely divided, which it carries on toward the sea. This amounts in a single year to as much as would make a cube of land a mile square and three hundred feet deep. The ability

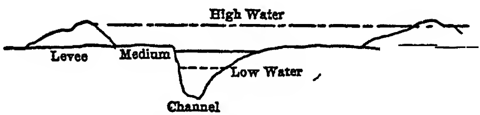
of a running stream to carry such a burden depends upon several factors, not yet entirely understood; but chiefly upon velocity and depth, with some modification due to the shape of the river bed. The Missouri, being a very swift stream, carries it along without difficulty. The Mississippi, however, has a much more gentle slope, and is only enabled to carry it by its greater volume and depth. In the course of almost countless years, during which a fairly constant régime has been maintained, it has extended its valley into the Gulf of Mexico and gradually altered its bed until it has established, from the rock shelf at Commerce to the mouth of its passes, a total length and slope which just enable it to carry this burden, approximately all of it at average stages, to the sea. For this purpose it not only winds back and forth across its major bed, as I have already described it, but in addition it makes these windings very crookedly, continually turning to and fro, sometimes in great horseshoes, so that in covering six hundred miles of air-line distance it flows through more than a thousand miles of channel.

Having established a bed which suits it at average stages, it is in its natural state continually modifying this to accommodate temporary stages. Thus at low water it deposits silt, filling up its bed — because of its inability to carry its burden — until it has so restricted its channel that its speed is quickened to a point at which it is again able to carry its load. On the other hand, as high water approaches, the proportion of silt carried by the increasing waters is reduced and the speed of current increased, so that the river, which now requires temporarily a larger bed, is able to pick up and carry along the silt which it dropped at low water. Both of these actions, however, are again modified by another feature; as the river rises it spreads out over considerable areas within its minor bed which the low-water flow does not cover. The outline of its main current is then altered, and it fills in with silt the deep trench constituting the channel, in certain broad reaches and crossings, and modifies its cross section to a considerable extent. As the river falls again and finds it necessary to seek its old and smaller bed, it cuts out these fillings and

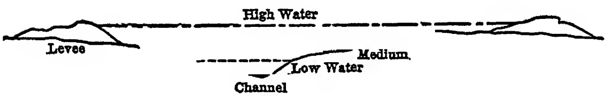
carries the earth in them on to some more convenient place of deposit.

It does not, of course, always happen that the silt which has thus been recently deposited is the easiest to pick up. The swiftest water is always the place of erosion, the slack water of deposit. The swift water in the river ordinarily follows the outside of every bend, and from the foot of each bend crosses over through a "crossing" to the head of the next. In a bend, therefore, the typical cross section is something like figure *a*, while in a crossing it is like figure *b*, and in the next bend below like *c*.

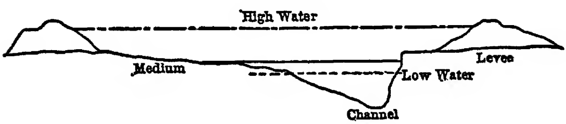
a



b



c



As the swiftest water is next the bank, it is often at this point that erosion takes place. Sometimes this erosion is all in the lower part of the bank, which becomes undermined, so that the upper part topples into the stream. Sometimes the whole bank is water-soaked by a long period of high water and then suddenly exposed and left unstable by a quick fall of the river so that from its own weight it falls in. In either case the river there becomes burdened with extra silt—often an excessive burden, which it proceeds to drop in the next crossing, where, as the current becomes more general through the whole breadth of the river, there is no part with speed enough to carry the burden. This work continues until the crossing is so blocked, and the length of the bend so increased, as to affect the slope of the river and check its ability to carry burdens. Often it spreads, by the deflection of the current, into the next bend. In this way a caving sometimes moves like a wave for a long distance down the valley, accompanied by a similar progress of foaming and moving bars.

It is owing to these characteristics that the

great swamps have had much of their influence. At the head of the St. Francis region the Mississippi rises in time of greatest floods about fifty-five feet above the low-water stages, which puts it about ten feet higher than the bank along the stream side. As it rises it first fills all of its minor bed, wiping out temporarily the channel, and flowing with some uniformity in the enlarged trough, readjusting bottom slopes and curves. As it rises higher it soon spills over at the head of the swamp. At once several things take place. The rise is checked temporarily until the region back of the bank is filled. The checking of the advance of a rise checks the current, not only in the part which overflows, but in the part which remains in the minor bed. That outside the minor bed deposits considerable matter along the river bank, and then, depositing less as it moves, fills up the back lands and flows slowly into the St. Francis River and sluggishly onward toward the mouth at Helena. The wave in the river itself passes slowly on, overflowing more and more as the rise continues to come, till it has filled the swamp, when it passes on down the river. In this

checking of the advance a considerable filling takes place in the minor bed, and this filling is chiefly in the part opposite the middle or widest part of the swamp. As the river falls again this filling forms something of a dam, through which it is necessary for the lower river to cut a new way. This new way does not always follow, in a natural state, the former way, and as a result there develops a region of uncertain channels in which the banks, cutting out to new shapes to accommodate the newly shaped low-water currents, are gradually driven wide apart, leaving such a broad and shallow stream, full of bars and shoals, as the notorious Plum Point region abreast the centre of the St. Francis swamp, or the Stack Island reach abreast the middle of the Yazoo.

Of course, in a natural state, as the river spills over the swamp, the crest is lowered, and the flow delayed. Although practically the same amount of water which passes Cairo passes Helena, if the flood is a short one the crest in the open river may pass Helena before the flood from the swamp arrives there; but if it is a long, slow flood, the swamp water may arrive in time to add a new

crisis at that point. In the course of this manœuvre a flood which stood 55 feet on the gauge at Cairo might be spread out in the St. Francis so that but 33 feet would be registered at Memphis; but Helena would see the flood there mount to 48 or even to nearly 50 feet. Vicksburg, again, where the Yazoo emptied, would also see nearly 50 feet, and at Natchez, where another large volume is concentrated, there would be almost as much.

Two hundred years ago, when the settlement of the Mississippi Valley began at New Orleans, the first dwellings were upon a bit of elevated ground which lay above all but the highest floods. In exceptional years, however, this sixteen-foot elevation was inundated; and to prevent trouble the inhabitants threw up low earthen ramparts to keep out the flood; these being known as levees, or raised places. As the fertility of the valley was tested and the river-bottom lands proved to be fabulously rich for sugar and rice, these walls were extended by individual planters up and down both banks of the river. In the lower lands they were of considerable height, sometimes ten or twelve feet; usually of steep slope and not strong,

but sufficient to keep out ordinary floods. They were thrown up by slave labor, often with logs and other foreign matter added to make filling easy, and were often broken — a break being called a "crevasse." They were sometimes overflowed. Later these walls were farther extended under local and state taxation, and about fifty years ago the federal government gave all the local overflowed lands remaining in public domain to the several states to be sold to create a fund for levee building and drainage. Under this act, by 1860 there was a very considerable wall all the way up to the mouth of Red River, and, after a short gap there, up the Arkansas side to Napoleon, at the mouth of Arkansas River. On the other side the Yazoo Valley was partly protected, and there were isolated levees below. The war made a long intermission in levee construction and repair. Before it was over marauding troops, cannon balls, and most of all unchecked floods, had made great breaches in the line. Long gaps occurred in many places. From Cairo to the sea there were only isolated places, such as the city of New Orleans, which were safely protected.

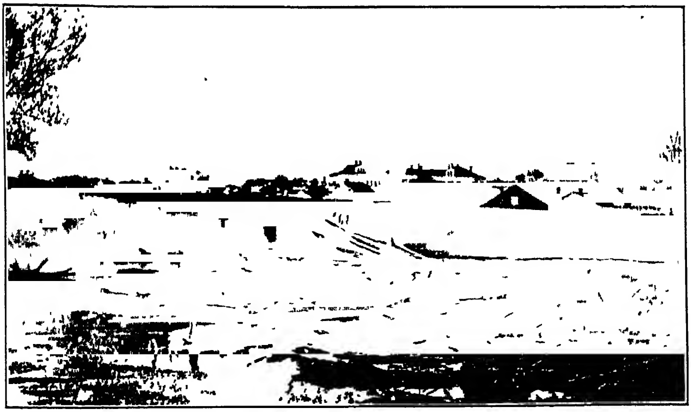
The whole swamp country was subject to every out-of-banks flood. And so prostrate was the country that as late as 1880 there was still to be seen the spectacle of the Mississippi forty miles wide, filling all of its major bed, sweeping on without other obstruction than cities and forests, from Cairo to the Gulf. By that time, however, systematic work on the development of the levee lines had been carried well forward, and these progressed steadily, so that by 1907 for the first time in the history of the valley a record-breaking flood, passing fifty feet at Cairo, went from there down the whole length of the channel without overtopping or breaking a single levee line, except a small and ancient earthwork a long distance below New Orleans. The St. Francis, the Yazoo, the White, the Atchafalaya, and the Pontchartrain basins all lay safe behind their levees, uninjured by the flow.

These levees, as will be shown when the manner of construction is described, are nothing more than earthen ramparts, varying in height from three or four feet in the lower reaches, to twenty-five or even thirty at exposed places; sometimes

five feet, sometimes more than two hundred in thickness. In general they follow the contour of the minor bed, at some little distance back from the stream, so as to protect as much as possible of the land in the swamp areas from overflow. But it has not been possible, with the limited funds at hand and with the dangers of bank erosion, to follow around the bends, or to keep in many places between the river and some inland lake or slough. Accordingly much land is left outside of them, and more is abandoned from year to year as the river shifts its course. Nevertheless the levees do afford protection to the land behind them in such degree that the products raised on the land in any average year return many fold the entire cost of the system for the past two hundred years.

During the erection of these walls many notable changes have been made in the flood régime of the river and many in its availability for navigation. Though the full effect of these is not yet felt, and there will be slight further modification before the final completion of a major bed exactly coinciding with the minor bed, it is possible

BEHIND A LEVEE



LEVEE PROTECTION IN FLOOD-TIME

now to describe the lower river as it will exist for centuries to come with some degree of accuracy. This river now flows in a major bed so restricted that at least twenty-five thousand square miles of its former area has been excluded from it. As a result, when a flood passes Cairo and spills over the banks, it comes at once to the earthen wall of the St. Francis levee system, which prevents its retreat over the swamp to the St. Francis River. There is, therefore, but a slight spilling, and the crest of the flood continues to rise and pass swiftly down the Mississippi in about the same shape as it passes Cairo. At Plum Point there is no shoaling and slacking, but instead a constant current that enables the engineers to maintain a deep channel through the intricate bars. At Memphis, instead of 33 feet as formerly, a flood rises 35, 38, and at last even 41 feet, with an assurance that some day it will go to 43, but an accompanying assurance that all that water will be within the banks of the river. At Helena there has been but a slight change, the concentration of the St. Francis and Yazoo floods raising the flood level on the gauge to about 54 feet. At Vicksburg it

has gone, with the closing of White River, to 53 feet, and from there down there has been no greater change. At New Orleans 16 feet has given place to 18 and this again to 22, and now the levee front of the city has been made safe to withstand a flood of more than 24 feet, beyond which it is not probable that even with all the tributaries in flood at once the river can come. Thus confined between banks, the flood waters flow with a steeper slope and greater speed; but being amply accommodated in the artificial major bed, they do little damage, and the crest moves to the sea more quickly than under natural conditions. It is noteworthy that so accurate is engineering knowledge of this part of the river, that the height to which a certain record flood would rise on the Memphis gauge when the St. Francis was closed was predicted definitely by the engineers before beginning the levee building opposite the city; and when the last gap had been closed and a flood of the foreseen magnitude passed Cairo, it rose at Memphis to within one tenth of a foot of the predicted height, and only failed to reach it exactly because of a crevasse

at Hollybush when the crest was approaching the city.

The building of levees has not been altogether unopposed by the people of the valley. As the closing of the successive swamps has limited the major bed and sent the crests of the confined floods higher, and as levees have had to be increased to meet them, the theory has been advanced, and has been quite widely accepted, that the river builds up its bed in proportion as the walls are raised, and that eventually we will be confronted by massive walls indefinitely high, between which will flow an elevated stream on a bed higher than the surrounding country. This is, of course, an absurdity. The mouth of the Mississippi at the Gulf is at a fixed level, and the river banks between which it flows extend with almost immeasurable slowness. The head of the lower river at Commerce is also at a fixed level, established by the rock rim there. Between these points the Mississippi is of a definite length, and that length, which it has established for itself in an age-long wandering, is just sufficient to maintain the necessary slope to maintain in turn the aver-

age stability of the banks of the stream with the amount of water and consequent current there is to be discharged. These conditions cannot be altered. If the river is shortened by a cut-off, its increased current eats into the adjacent bends and lengthens itself till it has again established its equilibrium. Any raising of the bed of this stream in any locality would at once cause a very decided change in its régime. The current above that point would be checked by loss of slope, and the current below would be increased and the whole river would be altered. If this continued for any length of time, we should have an absurdity in a river flowing along a level bed below Cairo for an indefinite distance and at last plunging over a precipice of mud into the Gulf. As the bed increased in height we would have the bottom of the river above the land and would have to use elevators to get up to low-water level. There is not the slightest evidence on which to base any supposition that any such raising of the bed takes place. The increase of the levees from year to year is due, as we have shown, to the contraction of the major bed; and the only known action caused by levees

in the channel and minor bed is in the direction of the elimination of the natural dam and pool régime and the establishment of a more even slope and a more regular volume.

CHAPTER IV

LEVEE BUILDING AND MAINTENANCE

THE levees of the Mississippi — and this applies to the whole system and not alone to the lower river — are nothing but earthen ramparts, built of the material to be found at hand, and designed according to the nature of this material and of the attack which is to be made upon them. There are along the bank three principal kinds of material from which to build, — clay, loam, and sand. Of these, clay is the best. Sand and loam have each their bad and their good points. Loam when very wet is apt to slump away entirely. Sand, on the other hand, is extremely unstable. Experience has demonstrated that a levee, to have permanent wearing ability, should have an eight-foot crown and slope away, in clay or loam, about one foot vertical for every three horizontal. If the levee exceeds ten feet in height, it is reinforced on the land side by a bench or banquette about eight or ten feet wide, sloping

away one on three to one on five, the banquette being from four to eight feet below the level of the crown. Banquettes are occasionally as wide as twenty feet. Levees built of sand are sometimes sloped on both sides one on five, this dimension being used in the Lake Bolivar levee at the head of the Yazoo system, a wall twenty-five feet high, having a base more than two hundred and fifty feet wide.

When such a levee is to be built, the line which it is to follow is first selected as a compromise between the ideal and the various rival interests at stake. An ideal line would exactly follow and closely neighbor the top of the lower bank. This is prohibited by the unstable nature of this bank except where revetment (to be later described) has been applied. Such a line would also be very long, and consequently exceedingly costly. It must be set back. This setting back at once brings the interests of the landowners into play, to have selected a line which will protect as much land as possible. The shaping of the current, the availability of material, and the security of the foundation must all be then considered. In

deep by twelve wide for a large levee, and intended as a bond between the levee and the wall. In some districts the earth which goes into this is puddled, in others it is merely packed. Then with scrapers and teams, or with men and barrows, or, as in some lower districts, with excavators and conveyors, he begins the construction. For this work barrows and hand labor are preferred and often stipulated, because they give a more solid and uniform structure. The levee is built somewhat wider than it is to stand, and larger in all proportions, first to allow for settling, second because it must finally be trimmed to dimension. No earth is allowed to be added on the outside to make up for a lack of dimension, as such an addition would slump away under flood pressure. The whole thing must be homogeneous. If the levee is being constructed with scrapers and mules, the animals are sent in a drove up and down the line at frequent intervals, to pack the earth. When the whole wall is completed and has been approved by the inspectors, it is trimmed to its larger, unshrunk dimensions, and is then allowed to settle slowly into size. Its surface is sodded with Ber-

muda grass, which gives a good turf, offering excellent protection against wind and rain erosion, and it is ready for use. Thereafter it is kept mowed, to prevent weeds from injuring it; it is protected against grazing animals, and though used as a footpath is forbidden ground to wheeled vehicles. If it is built of clay, it may continue to shrink beyond anticipation, and require that a wholly new layer be built up from the back, beginning at the base with a wide foundation and sloping up to and over the crest.

This levee work is done by the federal and state governments in partnership. Prior to 1882 the funds all came out of the taxes or the proceeds of swamp land sales. In that year the Mississippi River Commission, an organization within the War Department created for the purpose of improving the Mississippi, took up levee building as one feature of the improvement of navigation, and, except when positively forbidden by Congress, has continued that work ever since, spending nearly $1,000,000 a year on it. The several states have created levee districts in the swamp areas, each of which has a regular official

organization. These districts are enabled to issue bonds or certificates of indebtedness with which to pay for the work, and to redeem these have a sinking fund made up of taxes. These taxes in some districts are on every acre of protected land, in others on produce — fifty cents on every bale of cotton, and in proportion on all other material grown on land which the levee has reclaimed. In addition, they are aided by a general state tax. Of the $60,000,000 spent on the lower river levees since the Civil War, two thirds have been paid by the levee districts and the states at large.

Over all this work the Mississippi River Commission exercises supervision. In dividing its funds among the several districts according to their needs, it sometimes gives them the money for work, sometimes does the work itself. It has established a series of bench marks, from which it has based a so-called "M. R. C." grade, to which completed levees must conform, and this grade has been raised from time to time as the height of flood locally has been raised by the closing of the swamps. It has been the intention

to keep this grade three feet above the highest known high-water level. Of course the levees have never entirely reached this grade at any time, as it has been necessary to build the most important lines, and to protect the whole district through the years of lesser floods rather than protect a small part of it from the occasional record-makers. Consequently it has been the policy of the commission to allow the states to go forward with the building of these lesser levees, and to spend most of its own resources following this up by adding new backs and crowns to bring state levees up to "M. R. C." grade. At present this grade is actually attained in only a fair proportion of the lines; but the time is fast approaching when the whole complete levee will be brought up to standard.

Levee lines protect the lands back of them only so long as they stand intact. The moment a levee is overtopped or broken through, the break so made is quickly widened by the head of water against it, and a torrent flows through, inundating the land often for several hundred square miles, to a greater or less depth. Such a break is called

a crevasse. In time of flood the chief labor of the levee engineer is watching the weak points of his levee to guard against such a catastrophe, and some of the most exciting romance in the history of American engineering has been written in the actual reports of their doings.

A crevasse may be caused by many things. A muskrat or woodchuck, or even a crawfish, burrowing through the earth, may leave a hole through which the water may flow and start a leak. An old tree trunk left in the wall, or in the bank beneath it, may leave a cavity which fills with seepage water and causes a collapse. An underground passage, unsuspected, may be forced open suddenly by the head — often ten or twelve feet — of the water standing against the levee, and may boil up as a miniature geyser ten or a hundred feet back behind the wall. Sometimes a flood rises higher than the wall and overtops it. Sometimes, when the water is near the top, a cross wind makes waves which erode the upper layers and cause a crevasse. Sometimes, after a long flood, the water-soaked earth loses its stability and slumps flat away, — or more often a

part of the back wall caves away, preliminary, unless it is checked, to a total collapse. Against all of these things the engineer is on watch night and day during high water. Up and down the levee go the guards—often armed lest planters from the one bank may attempt to cut the levee opposite for their own greater safety. At strategic points, usually on the railway—for the railroad is as interested as the farmer in keeping the flood away from its right of way—the engineer masses carloads of lumber, sometimes of earth, and always of sacks. He has his men ready at call. The guards, pacing up and down, report at short intervals, and if one has found the seepage water in the ditch back of the levee increasing alarmingly, he reports accordingly. If a stream of clear water is found coming through, he gives an alarm and measures are taken to stop it. Such a stream, however, is not as dangerous as a muddy stream; for clear water is always slow seepage, while muddy water either comes through a hole unobstructed or else is full of eroded material from the levee. In either case the engineer may throw earth on the river side of the levee, hoping

it will be carried into the hole, — a measure seldom used, — or he may, and usually does, loop around the leak with sand-bags and earth, forming an inclosure in which the water gathers till it has head enough to check the flow.

If a sand boil occurs, it is either similarly looped or is beaten down with brush and masses of earth. The greatest danger, however, is from wave erosion along the top. For this purpose the engineer has carloads of boards and sacks, with which, on the exposed line, he hastily constructs a batter-wall, either as a small breakwater to destroy the force of the waves, or as a capping of sand-bags to prevent erosion. This is a matter most difficult of accomplishment. The destructive floods come ordinarily in February and March, when the water is extremely cold, and the men setting the wall or laying the sacks must often be knee or even waist deep in it for long periods. If sacks are being used, it is fairly certain that the land immediately behind the levee will be soggy from the same influences which have caused the flood, and the engineer must go some distance to fill his sacks, which must then be borne

on men's shoulders to the place where they are needed. If, as sometimes happens, there is danger of overtopping, the earth must often be taken from the back of the levee itself, — a dangerous expedient, — and piled hastily in sacks on top. By this means the Hollybush levee of the St. Francis was saved in 1907, though the river overtopped it for a quarter of a mile.

One of the most dangerous of all accidents is the slumping away of part of the back earth. The instinctive action of the green engineer is to heap more in the place it came from; this, however, is to court destruction, as the already water-soaked and weakened levee will ill support the additional burden. The safer and better way is to build, back of it, a well-braced wooden wall set against posts, and against this heap up earth, gradually bringing it to the foot and so to the slope of the levee, the whole being braced against the wooden wall. If this cannot be done, brush is thrown into the gap, and over this earth, preferably in sacks, is piled, the brush distributing the burden and preventing further slip.

At times all these measures and the most heroic

efforts of the engineer fail in the purpose, and a crevasse occurs. In such a case two principal lines of action are open to the engineer. He may attempt to close the crevasse, or he may devote himself to saving as much as possible of the levee wall from being torn away. If the levee is a low one, — and in Louisiana, in the neighborhood of New Orleans and below that city, this is most apt to be true, — there is often hope of a successful battle with the flood. But if the levee be a high one, or the flood standing high against it, such measures are most often futile, and the best work is that which stops the widening of the gap at the earliest moment.

In this latter case the engineer hurries to the scene large gangs of men, often contributed freely and gladly by the neighboring plantation owners, and carloads or boatloads of wooden scantling and timbers, together with bags and barges of sand from the nearest available source; for it must be remembered that when a crevasse has occurred, there is no longer earth to be obtained at the back of the levee, the inrushing waters having drowned out the whole neighborhood.

With a head of six to ten feet through the gap, the roar of the rushing waters can be heard for a long distance, and the end of the levee tears away in masses, falling with an increasing roar into the current. To attempt to erect any false work whatever during this first stage would be futile; but as soon as the first sign of slackening appears the engineer begins two moves, one to revet the ends of the levee themselves, the other to erect flanking or protecting dikes to prevent the current striking against the end. The dikes are erected some distance back from the end of the levee on the outer side. Timbers, usually four inches square, are driven as piling, usually by hand sledges, in four or more parallel rows, close together, and braced diagonally with scantling. These piling are connected into bents, and the successive bents are strongly braced to each other and equipped with a runway on or near the top. Often the current undermines and sweeps away this frail structure, but if it holds until completed the workmen then begin filling it with sacks of sand. The dike projects out perhaps a hundred feet, perhaps more or less, — sufficient, at any

rate, to provide a shield for the levee end from the current sweeping along the side. The sacks of sand are carried out on the runway and dropped by skilled men, in courses, the bottom one reaching out several rows each side of the dike to prevent undermining. Then as each course is added, the face of the wall opposed to the current is kept flush, but the back face is sloped in, so as to provide a gradual spillway on that side and furnish more adequate bracing. If such a wall holds, the next move is to revet the ends of the levee themselves. This is done by covering them with sacks of sand, sometimes hurled into the breach, sometimes lowered from ropes so as to lie exactly in place. The endeavor is to cover the exposed part entirely, to prevent further caving.

When both these tasks have been accomplished, there remains nothing for the engineer to do but to await low water and a time for repairs. The flood pouring through the crevasse will jeopardize no person, because it flows over so large a territory that it rises slowly. But it may cause much damage to land. An unrestricted rise of the river generally deposits more or less silt over the land

on which it stands; but a rush of swift water through a crevasse carries with it considerable sand, with which it may cover formerly profitable land to its entire destruction. Otherwise it causes no damage except as it is followed by malaria and as it delays the spring planting. A crevasse in summer destroys the whole season's crop, but breaks at that season are extremely rare. As the water outside the crevasse subsides, that which has passed in gradually finds its way back to the drainage stream of the inundated "swamp." If it is near cropping time, and quick drainage is especially desirable, as soon as the flood has subsided enough to make operations prospectively successful the engineer begins extending his old dikes or building new ones across the gap, and if these stand he fills them with sacks, and thus makes a temporary dam and allows the land to dry.

In the lower part, where gaps have been successfully closed, this same method is followed. The dikes, of timber bents, are extended from both sides in an arch, as wide often as the batture in front of the levee will allow, until they meet in

the centre, and gain a new stability from their union. They are then rapidly sacked up. The danger point in this work is at the centre, the gradual closing of the arch sometimes forcing the water to scour so deeply at the cap that the bents there cannot be made stable. This method was followed in one of the most famous bits of work ever seen on the river, the closing of the Conrad crevasse. But in a similar attempt, in 1903, to close the Hymelia crevasse near New Orleans, when the sugar lands were being devastated, it failed because at the critical moment a barge loaded with lumber slipped its lines and bumped too heavily against the cap of the arch, carrying away the whole structure.

The levee system of the Lower Mississippi is now fairly complete as far as regards the protection of the alluvial lands, though there are hundreds of miles yet to be brought up to the latest, and final, Mississippi River Commission Grade. As it stands, the levee of 1400 miles represents an investment of $55,000,000. To complete it to grade on its present lines will cost $10,000,000 more. If it could be held so, it would satisfy the

farmers and the states which lie behind it. Unfortunately, or perhaps fortunately, for the navigator, it cannot be held so. A large percentage is lost every year by the caving away of the banks under it, and new loops are continually being constructed around such threatened breaks. This costs heavily, and can only be finally guarded against by the use of revetment, such as will be described in the chapter on the minor bed. The development of the river for navigation also requires the use of this revetment, and needs also what the farmer desires but does not demand, the close proximity of the levee to the river bank even in the points-within-bends.

But before such a radical measure as this is adopted, there is a new need to be solved in levee construction. Levees as they stand are but walls of earth. A long flood standing against them lessens their resistance. Any small animal can cause an unsuspected hole in them and produce disaster. The least break destroys their utility for scores of miles. It is therefore essential that there should be added to the levee system some feature by which it may be rendered water-tight and

tight against the borers. Such a solution will probably be found in a concrete core, either set when the levee is built, poured in a trench afterward, or created by the driving of matched concrete piling. Steel and wood are useless in such a work, as the one rusts and the other rots away. But concrete endures forever. If it cracks in the settling of the levees it leaves but a tiny gap, through which only so much water seeps as will wet the ground immediately behind it. If the top of the levee is battered off by waves, it but uncovers the concrete wall, which stands firm. A boring animal will be turned back, or, if he finds a crack, go through a substance which will not cave off, and which prevents the hole widening to a crevasse. And more than all, the seepage through concrete will be so slight that the whole back half of the wall will remain almost entirely dry, and therefore permanently stable, so that there will be no sloughing off and no collapsing at critical moments.

Some such solution will be found, and in time the levee walls will be so constructed, close to the river, on both sides, and protected by permanent banks in front. The lands which they protect are

so fertile that from a bale and a half to two bales of cotton can be grown to the acre, and in corn, alfalfa, and truck they produce all the way up to $100 an acre a year. In fact, much of the land, cleared and drained, is already worth $100 an acre, and will before many years be worth much more. It has river and railway transportation facilities to many markets, and is certain to become one of the richest gardens in the world. If the St. Francis alone were completely occupied, and if it produced in a single year but $10,000 to the square mile,—and it is capable of more than quadrupling that,—it would yield in a year $60,000,000, or all that the entire levee system has cost to the present time.

CHAPTER V

THE MINOR BED: REGULARIZATION

THE principal object of the development of the minor bed of a river is the establishment of regular navigation. The accomplishment of this purpose requires that there should be created a channel which shall have at all stages, low and high, an adequate depth and width, not too sharp curves and not too strong a current for the economical transportation of cargoes. The depth of water over the shoalest bar determines the carrying capacity of the entire stream. Though interruption by ice during certain months, or interruption by shoal water in summer during a period which it is possible to predict with considerable accuracy from year to year, do not debar a river from profitable use, uncertain interruptions, the danger of occasional bars, the presence of unsuspected snags, or any uncertainty in the channel, instantly remove the river containing them from the list of secure burden-bearers to the

position now occupied by the Missouri and most other American streams. Money spent on such a river which does not take this into account may be spent for decades without profitable return.

This development of the minor bed is chiefly accomplished by measures which fall under two heads, regularization and canalization. Regularization, which is the method usually employed on soft-bottomed rivers and on streams which have ample water and gentle currents, consists in the erection of works of various sorts, which constitute or create false banks and directrices for the river, giving it a width so nearly uniform as to preserve a fairly even depth and cross section. Canalization, which is employed on the Ohio and on other hard-bottomed rivers or streams of little water or too swift descent, consists in the creation of a series of slack-water pools or canals, separated by dams, and connected, for purposes of navigation, by locks.

Methods of regularization differ in clear and in silt-bearing rivers. On the Ohio, where they are used as auxiliary to the lock and dam method, the works are built solidly, of rock and timber,

to act as actual false banks to the river. On the Mississippi, in which no such works could be given a permanent foundation, they are of frail construction, designed to persuade the river to deposit sand and silt about them, and so create a wall from its own store of material which will accomplish the desired object.

These works of regularization on the Lower Mississippi consist principally of two things: revetment, or false bank protection; dikes and other silt-arresting devices for filling in undesirable channels. By the use of these and certain accessories it is possible to obtain in this stretch of the river twelve, fourteen, or even a considerably greater depth at the lowest stage of the river, and to guarantee its continuity.

The manner in which the minor bed of the Mississippi winds to and fro across the major bed has been already described. Within this minor bed there is another groove, which crosses and recrosses it even more frequently than the intermediate groove crosses the valley. This is the channel, an irregular cut, in which flows the swiftest current of the river and in which travel

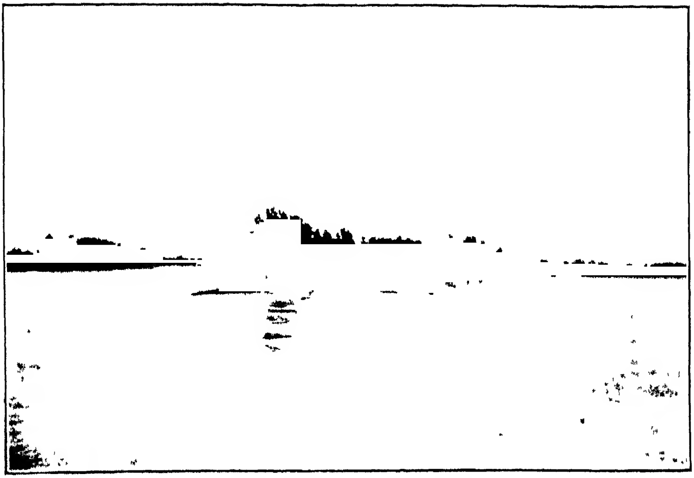
vessels using the stream. The current of the lower river varies, in the channel, from about two to about eight or nine miles an hour, the usual flow being about three miles, and the maximum attained only on the foreside of an advancing flood wave of extreme height. If a stream of water of that velocity be caused to flow down a sloping wooden trough, if it is started perfectly true down the centre and meets no obstruction, it will flow evenly all the way. But if it be started diagonally it will strike against one wall, and there reflecting will cross and strike against the other, and will continue this process as long as it flows in the trough. Though all the trough will be full of water, there will be distinctly traceable this swift curving line across and back, while in the nodes or places within the loops there will be still or slowly moving water which may be running upstream in an eddy if the outer current be swift enough. If this water be filled to its suspending point with silt, in a short time it will build a typical river-bed for itself, depositing earthen material in the nodes until it is as high, or nearly as high, as the water surface,

spreading a thin flat layer of silt or sand in the crossing where it goes from side to side, and keeping the trough scoured clean in a narrow strip where it impinges on the wall.

If the banks against which the river impinges be made of earth instead of wood, the speed of the water can be increased to a certain point without disturbing them. When it has reached such a speed that it becomes avid for silt, or has attained an abrading force which the banks cannot resist, it begins to eat them away, often undermining the lower part so that the upper falls in, and thus loading the river up with a new burden. The swiftest part of the current of this artificial stream is the portion immediately proximate to the bank. It is this part which receives and which can carry the burden. But as it approaches the crossing and the movement becomes more generally distributed in a greater breadth of water, this part no longer moves with such speed, and it begins to drop the extra load. So we shall see in our trough the crossings become more shoal as the bends are torn out. More than this, the tearing out of the bend bank alters the

shape of the stream. The current running out of it is deflected at a new angle, and strikes into the side of the next node above or below the crossing. It there finds a bank unadapted to receive it, and again eats it away, tearing up also enough of the bottom to form a new crossing channel in this direction. This altering movement will continue on downstream in a sort of wave, and the whole channel will continue to shift and change until the river has remained for a considerable time at an even stage in regard both to height and to speed, when gradually the banks will become adapted and stable and the stream will flow steadily in a true channel.

This condition of shifting channel, of moving bars, and of caving banks, prevails continually on the Lower Mississippi except in such places as the engineers have had money with which to prevent it. The main current sweeps with a mighty rush around the outside of bend after bend, crossing with less speed from the foot of one to the head of the next, each bend being curved in the opposite direction from that next above it. These bends often remain stable for years; and as often



AN ISLAND CHUTE, OPEN

A CLOSED CHUTE

continue caving year after year, gradually reaching back until the river has so lengthened its slope in them that it is no longer able to erode the bank. In this process of retreat it not infrequently happens that two bends — never contiguous, but separated by at least one reverse bend — approach each other, back to back, until either a flood pouring over the bank or the caving through of the last obstructing wall makes an opening and creates a new channel. This is called a cut-off. As there are usually eight to twenty miles of channel around the loop from side to side of this gap, and as the fall in that distance is from four to eight feet, the flood which pours through the new cut is naturally as destructive as that which bursts through a levee crevasse. In a short time, sometimes in five or ten minutes, the main channel of the river is pouring down through the gap and only a sluggish flow is left around the old bend.

Such a cut-off is a calamity not only for those who dwell on the land and for those who live by the now abandoned loop, but for rivermen as well. In the immediate vicinity of the cut-off the

river has an increased current, due to having an immensely steep slope in a few miles. This gives it the ability to tear out its banks. It has, moreover, entirely new direction of attack upon them. Both above and below it shifts and alters, tears out and builds up, and this process must continue for several years, to the destruction of channels and prohibition of any but the most hazardous navigation, until the river has again restored its condition of natural equilibrium; in which, at ordinary stages, it has slope and current proportioned to its bank material. Such a cut-off never shortens the river even locally for more than these few years, as the river must lengthen all its adjacent bends to "take up the slack" before it can settle down.

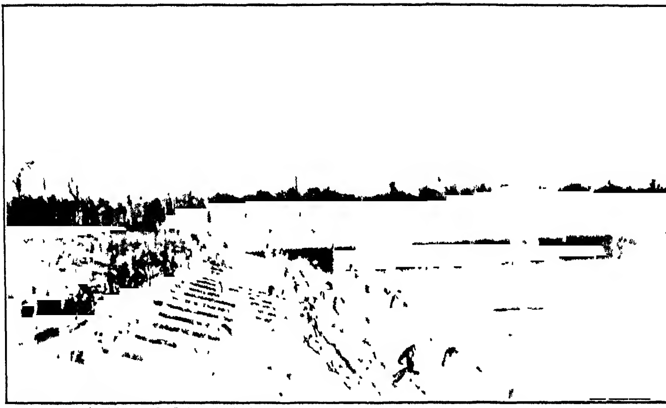
The interests of navigation, and equally of those who own the land on the bank, and those who live farther back but are protected by levees which in turn depend upon the stability of the bank, require that the bank in every bend shall be made permanent. Years of experiment and careful study of the river have developed an entirely adequate method of attaining this end,

known as "revetment." This process, as put to use on the Lower Mississippi, where it is found on a larger scale than anywhere else in the world, consists in protecting the bank below low water with a huge and continuous mattress woven of brush and galvanized wire; and preserving the bank above low water with a heavy facing of stone, brick, or concrete. The development of this process to its present stage has been one of the greatest attainments of the army engineers working under the direction of the Mississippi River Commission; and their success has been so complete that the permanency of the mattresses and the success of their operation are now a mathematical certainty.

To be entirely and finally effective, however, revetment must begin at a fixed point, where the river cannot shift, and proceed thence downstream, regularly, no bend being omitted, so that each may properly lead into the next below and receive from the next above. Nowhere has this yet been thoroughly attempted, as the investment of the government has only been sufficient from year to year to revet curves which were in especial

danger; and as a result the works have been attacked from above and from below by the river and millions of dollars' worth have been swept away. Nevertheless, in isolated bends along the lower river there are now existing more than a score of miles of such protection — out of a total of 400 or 500 which will be eventually needed, representing a present investment of about $8,000,000.

When a bend is to be revetted, stakes are driven along the shore on a line representing the zero contour, that is, they stand on the line that would be the water's edge at zero of the gauge, or normal low water. Mooring piles are then driven at the head of the bend, and to these are attached a series of mooring barges, set out normally from the shore, end to end, as far as the mattress is to extend. A common width on the lower river is 300 feet. Parallel to these and close below them are then moored an equal row of weaving barges, equipped with launching ways sloping toward the water upstream, and with working platforms and coils of wire cable at the head of the ways. Every bar and towhead of the



Photographed by Col. John A. Ockerson

WEAVING A FASCINE REVETMENT MATTRESS

AN EARLY TYPE OF WOVEN BRUSH REVETMENT

lower river furnishes abundant slim willows and cottonwoods, which spring up with amazing rapidity and provide an ever ready supply of material for the mattress weaver. These willows are brought in bargeloads and delivered to the weaving barges. Of large willow poles, and sometimes of timbers, and heavy galvanized iron cables, a "mat-head" is then woven, — a tightly wound bundle sometimes two feet in diameter, — to which are attached both temporary and permanent mooring lines, the latter carried ashore and fastened to sunken piling. This mat-head is lowered to the water, the weaving barges being downstream from it, and then the actual weaving is begun. The willows are bound in fascines, or bundles, usually in this river about one foot thick, the trees being two to four inches thick at the butt and about twenty feet long. They are laid with broken joints, butt to butt, and each fascine is lashed tightly to the mat-head or to the next forward fascine by the wire weaving strands which pass under two and over one, round and round, including at each turn the longitudinal cables which, uncoiling as the mat proceeds, are

carried the whole length of the mat to give it strength.

In addition to these, diagonal strands are sometimes included in long mattresses; and diagonal tree braces are also used. Willow trees slightly larger than those which make the fascines are lashed longitudinally along the mat for stiffening, and to form a hold for the ballast. As each strip of mat is finished it is launched, and the weaving barge drops aft, the completed part lying in an unbroken carpet on the surface of the water. As the size of the mat increases, the danger of losing it in the current becomes greater, and it is seldom they are made over 1000 feet long. The sinking of them is also a period of great danger.

When the whole mat has been woven, perhaps 300 by 1000 feet in area, the mooring and weaving barges are removed, and the whole lies afloat held by the permanent wire moorings leading upstream from the mat-head and from several points along its length. The mat is extremely closely woven but very flexible. Barges loaded with rubble stone are then brought alongside,—this stone being obtained from riverside quarries on the

Ohio and Upper Mississippi,—and the stone is thrown upon them, or rather laid carefully along what will be the upper side of the stiffening poles, until the whole mat is evenly weighted and just awash. Then more stone is brought down at the head and thrown on until the mat-head sinks. The current bears the stone barge down over the mat, and as it advances the stone is thrown ahead, sinking more of the mat. At this time a heavy current may buckle and destroy the whole, so that great care is necessary in manipulating the stone barges. An hour to three hours is usually required for putting the whole thing in place, where it lies like a carpet, fitting the irregularities of the river bottom, extending out well into the middle of the channel. Such a mat, in place on the bottom, represents an investment of about $19 a running foot.

When this lower bank protection has been completed a hydraulic grader is brought into play, and the upper bank is sloped away one on three, or a total sloping face of about 120 feet width for the average upper bank. When this has been graded evenly it is covered to the depth of two or three

inches with a layer of quarry spawls, or small chips of stone, and over this another thicker layer of rubble is spread, making the whole about a foot thick. Sometimes instead of this, however, wooden scantling is laid in pens ten feet square, and a layer of bricks laid in them, then covered with a wire mesh, another layer of scantling put on the pens, a thin cement thrown into mesh and bricks, and a top layer of brick put in the upper pen. Instead of this, again, sometimes single pens are used, and these are filled with a concrete made of cement and river bottom gravel, the whole bound with a wire mesh. And another expedient is that of using this concrete as an artificial rubble to spread over the bank without the pens. Each of these methods has been found useful, the simple rubble being as yet the cheaper, the others having increasing attractiveness for the engineer as he advances downstream, farther from his quarries. This upper bank protection costs in the neighborhood of $10 a running foot, making the whole cost of a revetted bend about $29 or $30 a running foot, sometimes reaching $35; but capable of being brought down, in

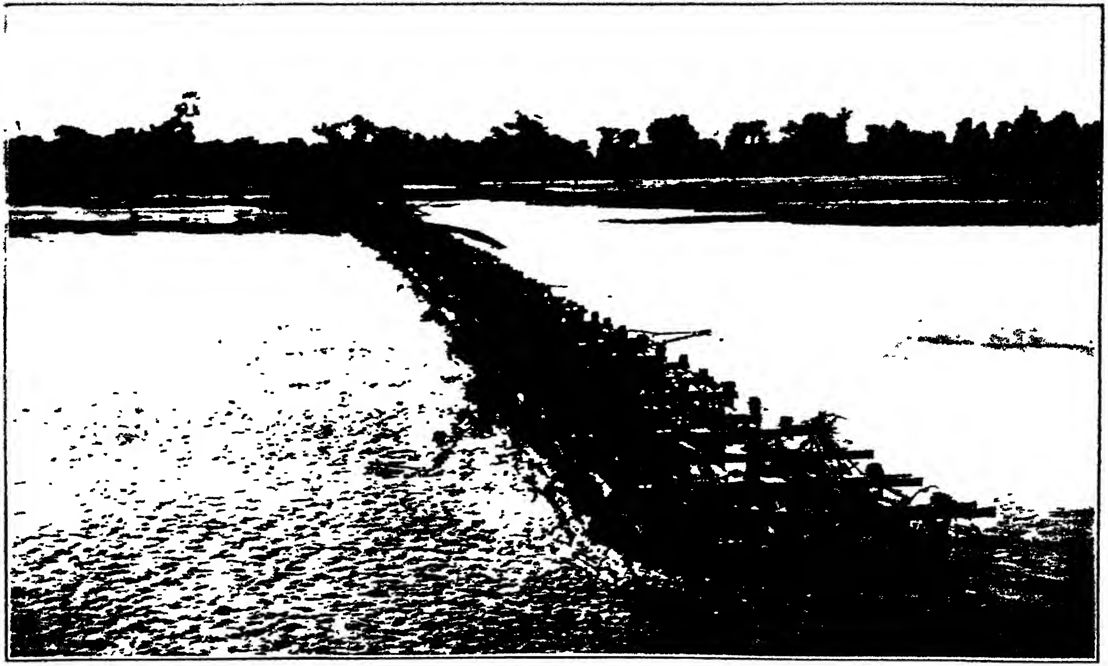
systematic and large workings, to less than $25 a foot.

Revetment of this character, though in smaller streams less costly, is necessary in every bend of every navigable river where there is danger of the bank cutting out and endangering either the channel or the levee. To become a successful carrier, a river must offer a channel as sure and reliable as the roadbed of a first-class railroad. It may not need as heavy or as broad revetment as the Lower Mississippi — there are few rivers as large and as deep as this to be so fixed. But from the head of navigation on the Missouri to the Jetties of Southwest Pass, and on all the principal tributaries, this must be the final resource in such a case. On the Lower Mississippi this means, with a very few exceptions, the revetment of the outside of every curve on the stream, in all a total somewhere between 400 and 800 miles, part on each side of the stream.

Revetment, however, is only one part of the improvement of a river-bed by regularization. It gives us a fixed shore for the stream at all points against which the river impinges. Its immediate

influence is to cause the river at its foot to scour deeper than it already is, a thing which is seldom necessary on the lower river, where these bends attain depths of more than 100 feet in the channel (below the lowest low water) even above Memphis, and are generally at least 50 feet deep below Cairo. Having these bends held with a firm bank so that they discharge the current on a certain tangent toward the other bank, it is necessary to contract and control that current in the crossing which it then enters, that that also may be dug deep by the stream. This is accomplished by several kinds of construction, most of which on the Lower Mississippi take the form of silt-arresting devices, such as brush hurdles, abatis dikes, and permeable fences, which check but do not stop the stream.

The proper path of the main current over a crossing having been determined, — by the use of floats, and by sounding, the river itself deepening the path which is easiest for it, — directing dikes are built out from the shore on either side to cause it to hold this course. On each side, or on either side, hurdles are constructed extending



A HURDLE DIKE, MISSOURI RIVER

straight out from the low-water bars into the current, at short intervals. These dikes are built of piling, well braced, and filled in with brush weighed down with rubble. About the foot and end of each is a foot-mattress, so called, woven of brush, well ballasted, to prevent the river scouring under them. Such a dike checks the flow of the water just enough to cause silt to fill in below and around it. If the dike is, or becomes, heavy enough to prevent the flow and make an actual head between the water above and that below it, it is apt to "blow out" or scour, destroying its usefulness. As a silt arrester, however, it builds up the land around it, and these filled-in areas, becoming contiguous, form a new shore line, holding the low-water current to a lesser surface so that it necessarily scours the crossing deeper. In some long and fairly straight reaches the current is thus forced from one side for a considerable distance over against a revetted bank opposite.

Abatis dikes, which were first used on the Missouri, consist of a frame of piling and timbers, set athwart the current in the part of the river which it is desired to fill. Braced under the up-

stream timbering and over the downstream, so that they slope downstream and upward at an angle of about forty-five degrees, willows are set thickly along the whole distance. The river runs through them easily, but they slacken it enough to retain its burden.

The aim of the Mississippi River Commission has been to restrict the river below Cairo to a fairly uniform width of 3500 feet. It has been unable to do this, for lack of money, but in certain regions it has expended large sums to this end. When it took charge of the river in 1879, there were two long-famous regions of extremely shoal water, namely, at Plum Point and at Stack Island. Plum Point is opposite the middle of the St. Francis basin, and Stack Island, at Lake Providence, is opposite the Yazoo. In each of them the river, annually silted up at high water, and annually seeking new crossings and channels at low water, had eaten at both its banks till they were from two to three miles apart, and the intricate crossings in between were shoal and blocked with continually shifting bars. Work in Stack Island reach was soon abandoned for lack

AN ABATIS DIKE AT LOW WATER, MISSOURI RIVER

AN ABATIS DIKE AT HIGH WATER, MISSOURI RIVER

of funds, and nearly all that had been done there was lost; but by gradual work there has been recovered nearly 1000 acres of land, built up by silt-arresting devices, and a channel has been established which, formerly three or four feet deep at low water, is easily maintained by occasional dredging to a depth of ten feet.

Plum Point reach, extending for sixty or seventy miles along the river on the Tennessee front, has always been the chief scene of the activities of the commission. There by miles of revetment, and by the use of hundreds of dikes and silt-arresting structures of many kinds, they have established a ten-foot channel easily maintained, and have shown the way to establish the rest of the river in similar regularity.

Some years ago, by direction of Congress, the commission began experimenting with dredges, and developed large possibilities by means of suction or hydraulic dredges, which pump up a mixture of sand and water and discharge it through long pipes, which either end in the slack water behind a bar or distribute the surplus material in some other out-of-the-way place. Al-

though a dredged channel is only a makeshift, no final plan for river improvement having been adopted, Congress later ordered revetment work abandoned except where necessary to save a levee, and has required the commission to build and operate a large fleet of these hydraulics. They are to be seen now, in every low-water season, patrolling the river. When the river begins to fall after a flood, the dredges are made ready. When the stream still stands at ten or twelve feet on the gauge, engineers are sent to those crossings from which trouble is anticipated, and soundings are made to show the trend of the channel. If it appears to be cutting out properly as the river drops, it is not necessary to dredge. If, however, a second sounding shows that the river is spreading too much, and not forming any one distinct channel, the dredge is called for. The engineer determines what appears to be the proper line for a crossing, and the dredge runs into this and makes a cut 200 or 250 feet wide through it. If the crossing is well chosen the river will at once adopt this new chute, and will broaden and deepen it and continue to cut it as

it drops. If it is unwisely chosen the river quickly silts it up and tries to break out elsewhere, and the engineer makes a new line and tries again. Generally but one or two cuts are necessary to establish a crossing, but sometimes three or four have to be made. In an average season from four to seven crossings have thus to be dredged between Cairo and New Orleans, to maintain a regular channel nine or ten feet in depth. In addition to the expense of maintaining a large fleet and dredging local harbors, this requires the annual expenditure of about $400,000. During the years 1907 and 1908 an experimental channel 14 feet deep, at first 250 and later 500 feet wide, has been maintained over a considerable part of the lower river.

The Mississippi River Commission has been in existence since 1879. Before that date there were some appropriations for snagging and general river improvement; but the following statement, which shows the amount appropriated to be spent by this body up to 1906, includes very nearly everything which has been expended between Cairo, Illinois, and the Head of the Passes,

toward confining the Mississippi to a proper major bed and making it develop a navigable channel in the minor bed. It must be considered in large measure a tuition fee, by which we have learned those things which it is necessary to do to establish fourteen-foot navigation from Cairo to the sea.

FINANCIAL STATEMENT OF THE MISSISSIPPI RIVER COMMISSION, JUNE 30, 1906

Expenses and salaries	$770,480.93
Surveys, gauges, and observations	2,237,850.62
Levees	20,612,317.06
Revetment and contraction, permanent channel improvement and protection	11,256,650.37
Dredges and dredging	3,903,642.19
Experimental dikes	100,000.00
Plant and miscellaneous	2,542,357.08
Improving harbors and tributaries, except Vicksburg harbor	6,370,460.01
Improving Vicksburg harbor	582,080.98
Works above Cairo	737,832.53
Total expended	40,114,380.77
Balance unexpended, June 30, 1906	1,384,040.30
Allotments available and unallotted	2,001,500.00
Total appropriated	$52,400,921.07

In addition to the demands of navigation, the complete revetment and final establishment of the Mississippi and its tributaries is urged by the necessity of preserving our valley soils. Where its banks are unstable the river eats at them al-

most continuously, sometimes traveling several miles through a rich land, sideways, eating up the old, rich accumulations of mould, and leaving on the opposite side sand barrens which will require years before they become productive. A steamboat journey along the river discloses for mile after mile the bank continually dropping, dropping, here a lump, there a hatful of earth; falling in, sometimes a yard or more, sometimes half an acre or even an acre at a slice. Such land is worth now, or would be if it had protection, one hundred dollars an acre. It produces easily that much in a year. In the future, as our country fills, this rich soil will be of almost fabulous value, and we cannot afford to allow it to be dissolved and its best elements borne in suspension or solution to the sea. In the end it will be this need of soil conservation, almost or quite as much as the need of channel definition and flood protection, which will force the complete revetment of the banks.

CHAPTER VI

THE RIVER MOUTH

THE Mississippi discharges its waters and sediment into the Gulf of Mexico by several channels, through a true and typical delta. In a channel averaging about one hundred and twenty-five feet deep, but in many places exceeding one hundred and fifty, between alluvial banks built up of its own deposit, it approaches the sea with a majesty and simple grandeur contrasting strangely with the hurly-burly with which it tears swiftly down its upper reaches. Unhindered by bar or island for the last three hundred miles, unfretted by snag or rock, rising and falling but a small fraction of its up-river flood height, it finds comfort in a bed which has not appreciably changed in centuries. It continues thus to a point more than one hundred miles below New Orleans. Then, widening out from the half mile which has been ample for the deep river, it shoals as it widens, until, when its banks are something over

two miles apart, the depth of water is but little more than thirty-five feet. At that point it divides into three branches, which extend like the toes of a duck over the map of the Gulf, narrow ribbons of water bordered by as narrow bands of land, and webbed between with marshes and shoals. These three branches are the main passes of the Mississippi: Southwest, into which flows about fifty per cent of the stream; South, which obtains little more than ten per cent; and Pass à l'Outre, into which flows the remainder. These, in turn, branch before reaching the sea. Southwest Pass, which is eighteen miles long, has several minor bayous emptying from it into the shallows. South Pass formerly gave one fifth of its water to Grand Bayou, now closed by a dam. À l'Outre divides into Southeast, Northeast, and many minor channels.

These Passes, as a rule, maintain an even width and depth from "Head of the Passes," where they are formed, nearly to the Gulf. À l'Outre, starting with about twenty feet depth, shoals as it divides. South Pass, before the construction of the Eads Jetties, was blocked at the head by a

seventeen-foot shoal, but below that retained a depth of about forty feet to its mouth, where, spreading out like both the others, it was blocked by a bar having but seven feet of water. Southwest retains a width of a third of a mile and a depth of from forty to fifty feet almost to the land's end, and there, widening as it comes to the Gulf, is fronted by a bar over which the natural depth of water has varied from eight to eighteen feet, and in the "palmy" days of clipper ships, when this was the great river mouth, was about sixteen.

Each of these Passes is flanked by soft but fairly stable banks of alluvion, on which grow grass and rushes and wild rice, and, in many parts, dense cane brakes and willow thickets. The off-channel banks are horrid with tangles of stumps and trees brought down by the current, but the channel side is usually well rounded and even. To the eye the Pass, away from its mouth and head, appears like a huge ship canal; and this, in fact, under the treatment of the engineer, is exactly what each becomes. The low-lying banks do not conceal from the traveler on the deck of

a vessel the marshes and the sea itself on every side; and from a masthead the whole delta formation is plainly visible. But from the surface of the water one sees ahead and astern a placid river, ending in a hazy mirage in which odd clumps of willows take grotesque shapes, and imaginary castles and houses mysteriously appear; while the banks themselves present impenetrable thickets of rush and cane and willow, which for all the eye can see might extend to the world's end.

Not all the water of the Mississippi finds its way to Head of the Passes. From the Red River to the sea there are many bayous, through which flood waters now discharge, or formerly did do so. The Atchafalaya itself, sometimes considered the former mouth of the Red, once took a large portion of the Mississippi's surplus to the Gulf, and still does receive a considerable part. Plaquemine and La Fourche have been closed up by locks so that the land along them shall not be inundated by the big river, and Manchac and others have been similarly treated. Bonnet Carré, where, in 1850, the river broke its bounds to pour, in an enormous yellow flood, into Lake Pontchartrain,

shows now an uninterrupted levee. But below New Orleans, as one nears Head of the Passes, there are still open channels. One of these, called the Jump, leads to a bayou, a route through which smugglers once made their way to Baratarian fastnesses, and by which fishermen and oyster dredgers still lead their luggers. The Jump is a civilized place now. The levee leads quite to its margin, there but a low-lying earthen ridge. Back of the levee are cottages, and back of them again orange and pomola trees, which bear rich burden. A little pier makes out, on which the crated fruit awaits the gasoliner. Perched on stilts across the Jump from the landing stands the deserted custom-house of early days; and beyond that nothing but the still untroubled jungle of the upper Delta, without levee or habitation. Not much water goes out this way now, though at one time there was a channel twenty feet deep into the bayou, and during the years of Captain Eads's work his steamboats entered here daily for willows.

On the other side of the river, not far below, opens a second, larger, and more picturesque es-

cape, called Cubitt's Gap, an old crevasse through which once much water went into Breton Sound, but which is now shoal and taking but little. This and the Jump, and "Batiste Collet's Canal," however, are but minor affairs. The bulk of the river comes down to the broadening at Head of the Passes, and flows out through the three great outlets.

To find a navigable route through this Delta to the sea was one of the great engineering problems of the nineteenth century. Upon its solution depended the commercial future of the entire central valley; and in the history of American engineering there is no more prolonged struggle between different interests, no more dramatic staging of the final action, than the opening of South Pass to navigation by James B. Eads.

In the old French days, Pass à l'Outre was, as its name indicates, the outlet channel for shipping. At its mouth was built a little village on stilts, with a blockhouse and pilot station, to which was given the name Balise; in the literature of fifty years ago a word synonymous with Louisiana, New Orleans, and the Delta. "Bound

for the Balise" was a current expression for all craft running to the Great Water, and in all river reference the word was as commonly significant of the actual mouth as Port Eads has been for the past thirty years.

In the old days the depth of water on the bar at the Balise varied from ten to fourteen or fifteen feet, sometimes even going deeper, and offering safe channel to the shallow craft in which the French and Spanish came to Louisiana. It was enough for the British gunboats which came to bombard Fort St. Philip in 1814-15, and it offered a good route for Captain Shreve in the steamboat Enterprise when he carried the British prisoners out to exchange them for our men on the fleet. But during the first half of the century it gradually shoaled, and that at Southwest Pass gradually deepened until the latter became, for the clipper ships, the only route. The pilots transferred their homes from the Balise to a little bayou running out from Southwest near its mouth, and soon a picturesque village, with a water street fifty feet wide, and bordered with palm trees and roses, came to be known as Pilot

Town. Over Southwest Pass bar went nearly all ships into and out of the Mississippi until the summer of 1877, and in the years of its use occurred some of the most memorable chapters of river history.

It was the custom then to carry cotton to Europe in swift-flying clipper ships, with sharp bottoms and projecting keels. These vessels were loaded with cotton frequently to a depth of eighteen feet, when it was well known that there was on the bar but sixteen feet of water at the highest tide. They left New Orleans in fleets drawn by big sidewheel tugs, and as they approached the bar were picked up by other tugs and pilots. These pilots sounded the bar daily, and were familiar with every spot in it, with the shifting of the current due to wind and tide and flood, with the accompanying changes in the bottom, and with every slightest sign of the moving of the channel. One of them, put in charge of a big clipper drawing two feet more than the channel held, would charge full speed at what he had determined was the "softest" spot. If good luck favored him he would find a

yielding bottom through which the thin keel of the ship would plough with ease, aided and borne on by the steady current. But if some mischance befell he would find hard sand, through which he might be able to go with a single tide, or need two or three tides, or, as happened in at least one case, spend three months or more in moving the ship across the narrow strip into deep water.

For a time, when there was keen towboat and pilot competition, steamboat captains would contract to pull a vessel across the bar, and must therefore stick to it day after day until she was across. Later, however, came a period of consolidation, the formation of the Towboat Company, and the establishment of a tremendously high towage rate per hour. Under this new rule, not only was a vessel compelled to pay for each hour she was towed, but additional for each boat that pulled her. Stranding for a day or two became very expensive. In spite of the enormously high freights on cotton, ships sought other ports, and those which had to use the Mississippi often attempted the bar without towing.

To meet this last resort, the Towboat Company

established a rule that no boat which attempted to go through without a tug, and stuck, should thereafter be helped off the bar by a steam tow-boat; and as a natural result of this rule, there began to occur frequent blockades of commerce, occasioned by some rash ship sticking in the best channel and holding every other boat up till she worked herself free.

Ships bound out often were able to work through what seemed impassable mud barriers, aided by the current which, flowing along their sides, channeled a way for them. Such an adventure befell in 1837, and is described in a letter from John Kershaw, Jr., to Samuel J. Peters, then president of the New Orleans Chamber of Commerce:—

"A ship drawing seventeen and one half feet forward and aft struck the bar of Southwest Pass in the true channel way; with the aid of her sails, kedge anchors, etc., she gradually prized ahead, and on the fourth day, to the consternation of those on board, it was found, she had only eight feet of water under her bow, whilst she had eighteen under her counter; however, by persevering in kedging, the use of her sails, and with the

aid of the current, she finally, on or about the twelfth day, carried before her this mass of mud, and drifted into deep water."

Notwithstanding the handicap which such adventures placed upon the commerce of New Orleans, the presence of cotton there, brought down in quantities by river steamboats, tempted vessels to risk the Pass. In February, 1859, when the trade of the city, so soon to be annihilated by the war, was at zenith, the export merchandise held up by grounding on the Southwest Pass bar was worth $5,367,339, including 72,000 bales of cotton, and not counting the value of the hulls; while import goods detained at the same time were worth $2,000,000. In the succeeding month there were thirty-five vessels inside trying to go out, and seventeen outside waiting to come in, while three, stuck in the fairway, blocked the channel. In the years from 1872–77 more than four hundred vessels were grounded there, and lost a total of almost a year and a half,—to be exact, 12,467 hours.[1]

"If you will come to New Orleans and go to the

[1] E. L. Corthell, *The Jetties.*

mouth of the 'river,'" said General Bussey of that city, to a congressional convention in St. Louis in 1873, "I will show you a vessel drawing but eighteen feet of water which has been lying there for the last three weeks, with corn on board worth forty-two to forty-five cents in currency, and then you will know why it is the farmers of Iowa, Illinois, and Missouri are impoverished and without money to pay their taxes."

"Two years ago," said John H. Kennard of Louisiana, following him, "I left New Orleans with a depth of water on the bar exceeding twenty feet, and, during the sitting of the convention that week I went to attend, a single storm filled up the passage four feet in a night, leaving but sixteen feet and a fraction.

"Only ten days ago, by order of the Secretary of War, I with a number of other gentlemen of New Orleans spent three days and three nights making a critical survey of this very ground. When we arrived at Southwest Pass there were lying thirty odd of the largest class of ships, representing almost every country of Europe, among which were some six or seven fine steamers. I con-

versed with captains of almost all. At the lowest calculation there were then floating in the mouth of that bar over $8,000,000 worth of property.

"We have a powerful corporation," he continued, speaking bitterly, "the Towboat Association, and they do not hold fasting and prayer when they hear a ship has stuck on the bar. They charge an enormous sum per ton for bringing these boats from the mouth to New Orleans, and in addition when these vessels get, as we saw those I spoke of, on the bar, they charge only $100 an hour for each boat that pulls at it,—and I am told they are very particular not to put too many on to begin with. In this case the steamship Bienville, running without a pilot, began the blockade, and when they do this towboats will not help them."

Next only to the Civil War, no other single influence had more effect in shaping the development of the transportation routes of the interior of America than this mass of mud across the mouth of the Mississippi. Had the channel into the Gulf deepened progressively as the depths of ocean vessels increased, the interior states would

have found this, their natural outlet to the sea, as sufficient for them in 1880 as it was in 1830. The railways as they came would have followed the main line of traffic, to New Orleans, or would have run east and west from the river as feeders; and the people of a prosperous valley would have demanded that the money which was really spent by the government on the construction of railways to bear their freights to the coast, should be spent on the development of these natural carriers for the same purpose. The traffic which would have resulted would have been north and south, its natural direction, rather than east and west. The depot for receiving imports and distributing them through the valley would not have been separated from the consumers by a mountain range; and the Eastern States, and especially New York, would never have attained that grasp on the business of the country which its railway power has given it. No corporation would have been able, as have certain railway interests in recent years, to monopolize the way to the sea by locking up the rail entrances to Manhattan, to Boston, to Philadelphia, and all the northeast-

ern tide-water. On the contrary, the very movement of cotton must have been more to the north via the lakes, to return value for grain; and the manufacturing centres of the upper valley must have found, that much the earlier, their eventual outlet through New Orleans to the Caribbean. All this must have been, and was not; for before the Mississippi was open to the sea, in 1877, the federal government had already given two hundred million acres of the public lands, and, in bonds and interest, $90,000,000 of public funds, to aid the construction of privately owned railroads to do the work that the public-owned rivers should have done.

This was not owing to sluggishness on the part of New Orleans or the West in making known their needs. Almost from the first day of American occupancy there had been foreseen the coming of the day when the channel would not suffice. Jetties were discussed and recommended by New Orleans business men as early as 1837. Later the plan of constructing a canal which would allow ships to come near the city without encountering the swift river current—a severe obstacle to sail-

ing vessels — became a favorite one, and the many bayous of lower Louisiana lent it attractiveness. The route through Lake Pontchartrain was only sufficient for small schooners, such as use it to-day; but there were other available routes, both east and west of the Delta.

Of these the favorite from the first was one by way of Breton Sound, connecting with the Mississippi by a canal near Fort St. Philip, seventy miles below New Orleans. Very few in the Crescent City, even as late as 1870, believed that the Mississippi's mouth could be kept clear; and this other route, avoiding the Passes and cutting off thirty miles or more of the river approach to the city, stood well in popular favor. As early as 1832 Major Boisson, a distinguished engineer of New Orleans, made a detailed survey over the route, and estimated that a channel sufficient for all that seemed apt to come that way could be constructed for $5,000,000. A united demand was made for this sum on Congress by the western, or rather valley, members, but it was finally adjudged too costly and was not undertaken.

When, in 1851, Major Humphreys began his

survey of the river, he also turned his attention to this project and conceived a liking for it, which two decades later led him, as Chief of the Corps of Engineers of the War Department, to one of the bitterest contests in river history. Still later, when, the war being over and the valley slowly recovering from the loss of trade, Congress saw fit to listen to the demand for a navigable outlet, the route was even more carefully surveyed by a government party, and a cost of about ten million dollars was estimated for the proposed canal.

The project in outline was to cut through the river bank at Fort St. Philip, and thence directly through the soft alluvion to the Sound, a distance of four miles. This cut was to be about twenty-seven feet deep and one hundred and fifty wide, and was to have entrance from the river through a massive stone lock large enough for the largest ships, and seven feet high, enough at that point to be above the highest floods of the Mississippi. The canal was to be flanked with levees, and protected from the Gulf by guard gates, and at its sea end would be extended by dredging twelve miles or more to deep water. There was then,

and there is now, no doubt that such a canal, if it could be maintained, would be the shorter and easier route for vessels between the sea and New Orleans. It would have, however, certain difficulties. Of these the first was the unstable nature of the soil, which would possibly not support the lock. The second was the habit of the river of depositing silt in every eddy, so that unavoidably the entrance to the lock would require constant dredging to keep clear, as would the lock and canal themselves. And the canal would be rendered temporarily useless by any wind which raised the level of the Gulf above the river. The freaky character of the river was a constant objection, for, though it seldom disturbs its banks so near its mouth, it might at any day swallow the lock and all, and having thus cut away the obstacle might find the thirty-foot channel to Breton Sound an easy way of going into the Gulf. This last was the real objection which gave them halt, for the people of the valley were too familiar with river habits to doubt that it could, if it took the notion, cut up all manner of tricks with any stone lock that could be built.

Nevertheless, General Humphreys continued to urge, and to be supported in urging by nearly all New Orleans, the opening of this canal. In common with other army engineers he had studied the jetty systems used abroad, and in particular that of the Sulina mouth of the Danube, the stream which, in sediment borne, in current, in mouth, most nearly of all in Europe resembled the Mississippi. At the mouth of the Sulina parallel piers of masonry had been extended through the bar to deep water. The current contracted in these had scoured its bed to navigable depth, and most of the silt thereafter carried out was swept away by a cross current in the sea.

In his investigation of the Mississippi Humphreys had been led to believe that there was carried out to sea by it, not only the mass of material which it holds in suspension, but also a great amount of gravel and coarse matter which is rolled along the bottom. This bottom material, he believed, was dropped over the edge of the bar in such a quantity that it would extend the bar out three hundred feet or so each year. He believed that the river, flowing out upon a bed

of salt water beyond the bar, left under itself a "dead angle" of salt water, in which there was no current either way, and into this not only the rolled matter but the sediment would instantly drop and accumulate, if it were not allowed to drop on the bar itself. On this account he believed the jetties would require millions in extension each year, and would never be satisfactory, even if they could be constructed and maintained, which he did not admit, or could scour a channel, which he denied.

To confute these theories held by General Humphreys, came forward James Buchanan Eads, the man of all men most likely to stir up opposition in an army engineer. In the first place he was not only a civilian, he was not even a schooled man, having learned what he knew from books borrowed in boyhood from his employer, and later bought as he needed them from his earnings. He had constructed at St. Louis a bridge that older engineers had said could not be built, by methods which they had asserted would not work. He was a daring, clear-headed, practical man of large experience in engineering work,

a pioneer adventurer by nature, whose enterprise led him into many lands, and who had the courage to attempt of his own initiative whatever, regardless of precedent, practical sense told him could be done. He had spent almost a lifetime on the river, and had walked in his diving bell over nearly every foot of the bed from Vicksburg to St. Louis, examining and salving wrecks. He had devoted himself to the subject of erosion, and had determined to his own satisfaction that the power of a river to bear sediment in suspension was a function of the current, and varied somewhat with the depth. From all his studies and from his knowledge of the river, Eads believed that jetties could and should be built. He pointed out that the canal, if constructed, would be soon outgrown, that it would require slow passage, and that when ships became numerous it would perhaps detain them hours or days, waiting their turn through. A slight accident to the gate would put it out of commission. On the other hand, once open a pass to deep navigation, and every vessel could come through at full speed, without delay. It could be done,

he said, and if done would be the only satisfactory solution.

Accordingly, in February, 1874, Mr. Eads made a formal proposition to Congress by the terms of which he agreed, if permitted, to open Southwest Pass to navigation at his own risk, to be paid only when he had succeeded in accomplishing this so-called impossible feat. He guaranteed to establish a channel twenty-eight feet deep through Southwest Pass into the Gulf of Mexico, for ten million dollars. Of this sum he was to be paid the first $1,000,000 when he had deepened the way through the bar to twenty feet, and an additional $1,000,000 for each additional two feet, until when he had secured a twenty-eight-foot channel he would have received $5,000,000. The remaining $5,000,000 was to be withheld and paid to him in annual installments of $500,000, to guarantee the maintenance of the full channel depth for ten years.

No fairer proposition was ever made to our government than this. That it was made by Captain Eads out of love for the river itself, and for the country which demanded the outlet, rather

than from hope of great profit, there can be no doubt; for the estimate of cost of the Southwest Pass jetties, presented to Congress by a board of engineers convened for that purpose, was $16,000,000. Nevertheless, Eads's perfectly safe offer called forth immediate and most bitter opposition.

To understand this, and the subsequent fate of the Eads plans, one must have a comprehensive realization of the situation in New Orleans at that time.

In the first place river traffic, which had reached its greatest prosperity just at the opening of the war, at a time when Western railway building was in its infancy, sprang to life again in 1865, to find that the five intervening years had seen railways and the railway spirit advance with remarkable speed, while the river had been allowed to go to the dogs. There had never been much done by the federal government to improve the channel. Snags had now accumulated unchecked for years, the bars had shoaled, the levees were gone, the banks were untended, the river was a chaos. Navigation under the circumstances was

perilous and costly. At the same time the Western country was filling up with enormous rapidity, the crops to be moved were every year becoming heavier, and the demand for an outlet to the seaboard louder and louder. River boats were hauling grain for export nearer and nearer to the actual cost, yet seeing more and more of it go eastward by rail, because the big steamships running out of New York could carry it to Liverpool so much more cheaply than those which struggled through the bar at the mouth of the Mississippi. The typical river-man of those days — and of to-day — is no great believer in engineering control of the channel. "Take out the snags and dredge it on the bars," he says, "and we will get along as well as we can. You can't control the Mississippi."

That was his view with regard to the part of the river on which he sailed, and it was his view in the matter of the Passes. "You can't control them," river-men almost unanimously asserted. But the outlet to the sea must be opened, so that by reducing the ocean freights to a parity with those from New York the river could claim its

trade. An outlet for the deepest ships there must be. But as it was impossible to control the Mississippi at its mouth, this outlet must be a ship canal, open at all times and free from current. So tremendous was the feeling on this point, that, when there seemed likelihood of the Eads proposal being accepted, the following extraordinary appeal was sent from New Orleans to Congress:[1]

"Would you, can you, honorable Senators, at such a moment, contemplate or tolerate the half-insane proposition of strangers, who can know nothing of the habits of our inexorable enemy, to dam up his waters at the mouth by jetties or wing-dams, that must inevitably send back the flood waters like a tide to the very city of New Orleans, or beyond, and complete the impending destruction? Of this result we assure you, with an earnestness ground into us by a lifelong experience and observation, and by all the lights that science and professional investigation are capable of lending us. Do not, we pray, permit us to be destroyed, and that without remedy."

Under such pressure the Eads bill, reported

[1] E. L. Corthell, *The Jetties.*

favorably by committee, was set aside in the House, and a bill authorizing the immediate appropriation of $8,000,000 to begin the St. Philip Canal was passed instead. But in the Senate the straightforward presentation of the case by Captain Eads had more effect, and the whole matter was laid over until a specially appointed committee could report. This commission, consisting of seven engineers, three from the army, three from civil life, and one from the Coast Survey, visited all the principal river jetties of Europe, and went thoroughly into that subject as well as making an exhaustive study at the mouth of the Mississippi. It reported three plans for solution (report presented to Congress, January 13, 1875). The Fort St. Philip Canal, to be 27 feet deep, 200 feet wide, and with a lock 500 feet long and 65 feet wide, would cost $11,514,200. Jetties at South Pass would cost $7,942,110, and jetties at Southwest Pass would cost $16,053,124. Of these they recommended the jetties at South Pass, on the ground that they would cost less, could be constructed without disturbing the existing channel at Southwest Pass, or otherwise

interfering with navigation, and could be built more quickly. They recommended that, whatever plan was adopted, the whole sum be made immediately available, so that the work could be pushed forward to completion as quickly as possible.

With the recommendation for South Pass Mr. Eads did not agree. He protested to Congress that the work there would be more difficult, because of the shoal at the head of the Pass, which would require work at that end as well as at the mouth. Moreover, so little water went out there that he doubted the sufficiency of it to maintain a thirty-foot channel, which was the required depth. It was certain to become eventually insufficient for the commerce of the valley. Southwest Pass, big, abundant, the natural outlet, appealed to him as the only sufficient one. Accordingly he made a new proposition to Congress, that he would build the jetties at Southwest Pass for $8,000,000, and would maintain them for twenty years at an annual cost of $150,000 (the commission had reported that the annual extension to keep in advance of the bar would cost

and expense. When he had deepened the channel to be twenty feet deep for a width of two hundred feet, he should be paid five hundred thousand dollars. Another two feet would bring a like amount. Two feet more and fifty feet wider should bring him a similar sum, and if maintained a year, $250,000 additional. A twenty-six-foot channel, 300 feet wide, would bring another half million, and a year later, if maintained, $250,000. A twenty-eight-foot channel, 300 feet wide, would be ground for another similar payment, and for a channel 30 by 350, half a million at once and another half million at the end of a year of maintenance, a total of $4,250,000. Thereafter Captain Eads should maintain the channel at that proportion by jetties and auxiliary means for twenty years, for which he was allowed $100,000 a year, and during that time the government held up as guarantee the remainder due him, $1,000,000, paying him five per cent per annum semiannually, and paying $500,000 at the end of ten years and the other $500,000 at the end of the twenty if all went well.

It is, of course, perfectly evident that no man

not absolutely sure of himself would have undertaken the task on such a contract; it is equally certain that no man with less enthusiasm for the work than Eads could have impressed its possibility upon others, and secured the funds to finance what was considered by many engineers to be an impossible plan. Nevertheless, Eads at once signed a contract with the great firm of James Andrews & Company to begin the actual construction, they agreeing to furnish the necessary quarter-boats, floating and fixed plants and material, and not to ask for the first payment until 50,000 cubic yards of mat and 10,000 cubic yards of stone were put in place. They would then receive half the agreed price for that work, the rest to be paid when Congress had made certain payments to Eads. The firm charged such prices for the risk that the contract was made only to a twenty-six-foot depth of channel. To provide the money and push the work, Mr. Eads organized the South Pass Jetty Company, a purely financial corporation, which agreed to furnish $200,000 as needed, on which it required to be guaranteed ten per cent interest and one

hundred per cent profit. Additional sums of money as needed from time to time were raised at equal or even more exorbitant rates.

It is extremely difficult for one unfamiliar with the delta country to picture South Pass, as it is now or as it was when Eads took charge of it, in June, 1875. Within ten miles of the lighthouse at its mouth there was not a building of any sort except a few fishermen's shanties. Within one hundred miles there was not a foot of ground which was not at some time subject to overflow from river or Gulf. Standing in the top of the lighthouse one could follow to the northward the gentle curves of the canal-like pass, between its willow-clad marshy banks, to the point where it merged with Pass à l'Outre and Southwest Pass, coming in, in like willow-bordered ribbons, from equal angles to the east and west. It was a natural ship canal, and in its whole ten miles of length was not a shoal spot, a sharp turn, a dangerous bank, nor a snag.[1]

Small as it appeared in comparison with the larger passes, each of which has five times its

[1] E. L. Corthell, *The Jetties.*

volume of water, it would anywhere else be considered a magnificent river. The average width of the Pass, which Eads hoped to preserve, was about 700 feet, and the depth, except at the ends, nowhere less than 30 feet; but as he believed the erosive action of the tides would be considerable, he planned to put the jetties a thousand feet apart. Halfway its length the right bank of the Pass was broken by the opening of Grand Bayou, by which a fifth of its water was discharged into a bay to the west of the Pass. In its centuries of formation and flowing South Pass had, in most of its length, exactly shaped its cross section for the amount of water it carried. This cross section permitted it to bear to its mouth the burden of silt which was its share. At the end of its banks, however, it met a littoral current setting toward the west, in conflict with which, and in consequence of its arrival at sea level, it dropped its burden; which, by the current and the waves and winds, was piled up about its mouth, more on the right than on the left of it. This accumulating mass formed a bar over which the river spread out, and year by year more and

more of the bar was raised above water by the addition of silt. These parts thus raised were at the sides of the stream, and formed natural extensions of the Pass, continuing to encroach until they so narrowed the pass between them as to form a cross section equal to that above. When that stage was reached, the current had eroded the bar between these two extensions (the actions were simultaneous) to its full depth, making a complete extension of the canal, and, by carrying this eroded material seaward, continually shoving the bar farther to sea. This was, in fact, the process of delta building which had been going on for countless centuries, the river keeping just ahead of it a bar, of which it made more land and through which as it did so it extended its length. The plan of Major Eads, and practically the whole plan, was to anticipate part of the action of the river, and make the river do the rest. He would build artificial banks, beginning where those of the Pass had reached stability and carrying them out to the far edge of the bar; these would so narrow the river that it would forthwith scour a thirty-foot channel

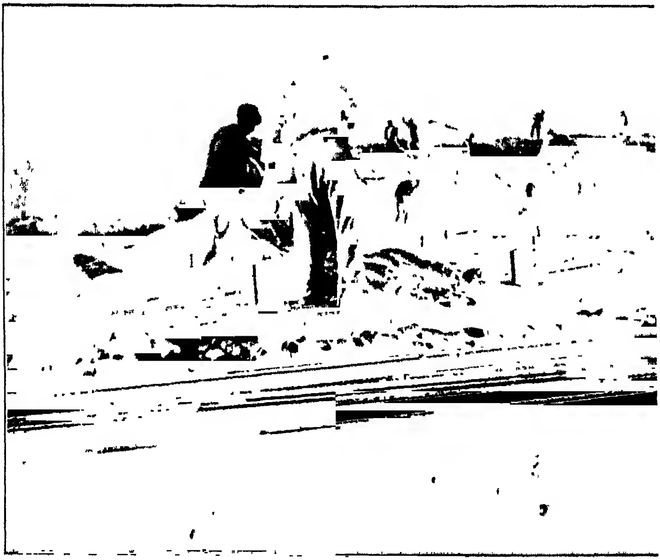
through the bar. Even most of his opponents admitted the feasibility of this, but they asserted that the material so eroded, with what was regularly brought down by the stream, would build the bar up at the seaward end faster than the jetties could be extended; while Eads maintained that the littoral current would move this away fast enough to keep the channel clear with a minimum of dredging and extension.

The Jetties, or artificial banks, with which he planned to do the work, were to a certain extent modeled after those at the Sulina Pass of the Danube, but were much modified to meet the requirements of the situation. They were to be of the simplest construction. Mattresses of willow brush, gathered from the abundant thickets along the Pass, Grand Bayou, and the river, were to be woven on ways built at the spot, towed into the line surveyed for the walls, and sunk by rubble stone. Over these more mats would be sunk, as the whole settled into the silt, until a stable foundation had been made which held its crest above water line; and on this a concrete or stone wall would be established. The east jetty, as surveyed,

extended from the land's end 1200 feet south-easterly, then deflected to the west, one foot in 23 for 2800 feet, then one foot in 16 for 4100 feet. There a curve commenced, still to the westerly, with a radius of 11,720 feet in chords of six hundred feet to make a total length of 12,100 feet, or nearly 2⅓ miles. The land on the west side of the Pass extended farther seaward, and the jetty on that side, paralleling the curved part of the east jetty, was only about two thirds as long.

Most of the willows for the mats were brought from the bayous opening from the "Jump" channel above Head of the Passes. The mats themselves were woven on launching ways erected for the purpose on the east shore of the Pass near its end. Each mat was 100 feet long, and the lowest in the foundation were 40 feet wide. These were founded upon a framing of yellow-pine timber, 2.5 by 6-inch scantlings, spliced to full length, running lengthwise the mat and spaced five feet between centres. Hickory pins were wedged and trenailed into these strips so as to stand upright when in weaving position. The

PEGGING AND FINISHING A MAT



MAKING A JETTY FOUNDATION MATTRESS

willow brush, fifteen to thirty feet in length, was then brought and laid upon these strips at right angles with them, the brushy tops overhanging the frame about three feet. This layer was made about sixteen inches deep, and then a second layer at right angles put over it, three inches above the tops of the pins. Cross strips similar to those running longitudinally in the bottom were then set over the brush, with holes bored for the hickory pins, and forced down upon them and the pins wedged in place. The whole was strengthened by longitudinal bracing. At the corners of exposed mats additional iron screwbolts were used as well as pins. The whole was then launched. Mooring piles marked the line of the jetty, and the end of the last sunk mat was also marked. The new one was towed into place and sunk in the manner described in the chapter on bank revetment, by throwing on stone from a barge. It was possible to make a mattress 100 by 35 by 2 feet in two hours. The method and type of making were the invention of Colonel Andrews and Mr. Eads, and were patented by them. A great part of the credit of the jetties is due to this type;

for this simplicity and ease and cheapness of construction made possible the carrying out of the great contract.

It is not necessary in a work of this character to go into a full technical description of the progress of this work. At the end of the first year the jetty walls were simply uncompressed walls of willow mattresses, but when the river rose in January, 1876, the flood, finding its way to the sea obstructed, attacked the bar with great vigor, deepening the centre line of channel most of the way to twenty feet or more, and at the outer end, where there had been but nine feet of water, diminished in October, 1875, to 7.5 feet, it scoured to seventeen feet.

So rapidly was this work accomplished that Mr. Eads was able to celebrate the first anniversary of the passing of his enabling act by sending a ship to sea through the new channel. On March 4, 1876, the Mattie Atwood, a three-masted schooner carrying 2150 bales of cotton for Revel, Russia, went to sea through South Pass, drawing 13½ feet of water.

A few weeks later Captain E. V. Gager and

Pilot Richard Francis brought in through the new channel, without touching bottom, the Cromwell line passenger steamer Hudson, from New York, passing in at low tide on a draft of fourteen feet, seven inches. From that time on, though there were difficulties, the progress of the building was looked upon with confidence by shipping interests.

The willow walls which were erected as prolongations of the Pass settled gradually into the soft bottom, and were covered by more mattresses, and at last upon the top of all a great wall of concrete blocks was built, the usual formula being 3 parts cement, 3 parts sand, 3 parts gravel, 15 parts broken stone, the heaviest single blocks weighing over 260 tons. The concrete work on the east jetty extended about one mile, and that on the west half a mile, at the sea end. The mats back of them were compressed with rubble stone.

While this work was being carried on at the mouth of South Pass the engineers and contractors had been equally busy at the head of the Pass and at Grand Bayou. The latter was closed by an ingenious dam, composed of a framing of

stout piling and heavy timbers, against which were placed willow mattresses not unlike those used for the foundation of the jetties. These were, however, woven loosely, framed stoutly, and made in small sections. Floated to the site of the dam, one edge of a mat was brought to the edge of the piling, and was raised a few feet above water level by a pile-driver. The current immediately caught the other edge and drew it down against the piles or against the bottom, and held it there. To prevent scour the bottom was floored with mats and riprap. The current obstructed in passing through the willow dam deposited silt, and in the course of time entirely closed the channel. Similar work was adopted at Head of the Passes. As a precautionary measure, to prevent the narrowing of South Pass from diverting water to the other Passes, a mattress sill was laid across the mouth of Southwest Pass, from shore to shore, to prevent enlargement, and a similar mattress across the entrance to Pass à l'Outre. But the greatest work at the Head of the Pass was the construction of contraction dikes and deflecting dams, to narrow the channel

and insure the direction of its proper flow through it. The entrance to South Pass was broad and shoal, with a small island directly in the middle of it. In the deeper approach, on the southwest side of this island, there was about fifteen feet of water at the time the jetty building began. It was, of course, necessary to take immediate steps to increase this depth and establish an open channel, to obtain the benefit of the jetties themselves.

This was accomplished by erecting a dike, called Lighthouse Dike, on the point between Southwest and South Passes, to hold that point and direct the flow, and then by creating a large work consisting of a dike extending straight upstream from the upper end of the island, parallel to and about 1000 feet from Lighthouse Dike, but running about 4000 feet to the head of the obstructing shoal; there it connected with a cross dike called the "upper dam," extending about 1700 feet in an easterly direction across the shoal into the deep water of Pass à l'Outre. Another dam, about 1700 feet above the head of the island, ran easterly to connect with a dike which extended from the shore east of the island north-

easterly to the end of the Pass à l'Outre sill. Last of all, a dam crossed the to-be-abandoned channel east of the island. The whole thus formed an enormous silt-gathering obstruction designed to create land in the area between South Pass and Pass à l'Outre, reduce the amount flowing into the latter, and insure both the flow and the depth of South Pass entrance.

This plan was in large measure the result of a financial necessity. The first plan had been to deflect the water by the dike known as East Dike to the channel east of the island; but success by this plan was slow in coming, money was giving out, and Eads had not yet been able to get through the War Department any official statement of his success on which to base an appeal for financial assistance. The only evidence he had that the channel was improving was the continual passing of the Cromwell steamers, for which there was enough water west of, but not east of the island. To continue to accommodate them was his only hope of safety, and to do this it was necessary to keep open the west channel. On this account chiefly the plan was modified, the whole

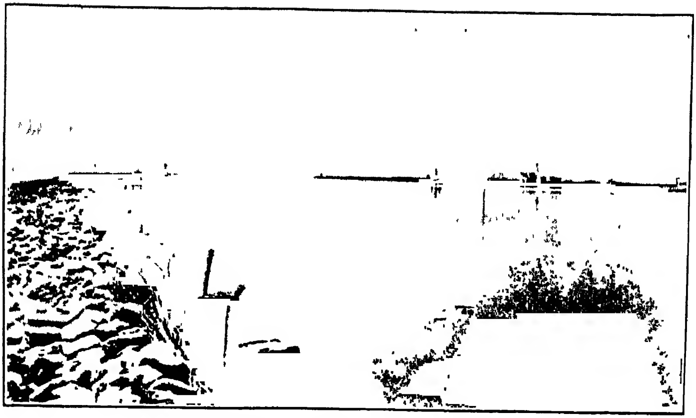
expense of the East Dike being by the new plan practically needless, and the long island dike was built instead.

The dams, erected in a stiff current, in a soft bottom, and with their progress interrupted by high water, were of the same type as that at Grand Bayou. Piling and timbering made a heavy foundation or frame, the front strongly braced against a rear row of piling. Across the front of this frame mats were stood on edge as at Grand Bayou, and at their feet other mats and heavy stone revetment prevented scour. The dikes were of mattress construction, similar to the jetties, though without the heavy concrete overworks necessary at the sea end. This work was begun in June, 1876, and carried quickly to completion. In September of that year, to insure the greatest benefit from the work and prevent any enlargement of the other Passes, a dredge was set to work on the shoal at the head of the west channel, and an eighteen-foot cut was made. By February, 1877, there was a least depth of 22 feet on the shoal, and a twenty-foot channel 110 feet wide. The whole shoal seemed to be moving

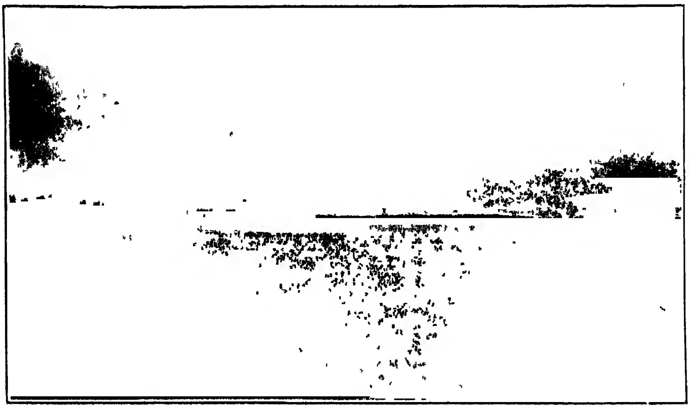
out bodily. By March 7 the twenty-two-foot channel was everywhere 200 feet wide, and 23.9 feet draft could be carried from the river over the shoal into the Pass. The channel continued to develop rapidly, and by June 6, 1877, 414,400 cubic yards had been scoured out of this shoal.

All of the earlier work on the jetties was done as hastily as possible, and often with so much economy at the sacrifice of strength as to cause serious loss from the failure of piling and of dams. This haste was due to the necessity for getting decided results in a deepened channel, to make certain the financial side of the venture. That it was successful is shown by the fact that in February, 1877, Captain Eads received the first payment, of half a million dollars, for a channel through the Pass twenty feet deep and two hundred feet wide.

Yet though South Pass had become the chief navigable outlet for the river, the progress of the Eads partners toward the fulfillment of their contract was still balked in many ways. Official surveys were delayed, and the money became so short that at one time the payrolls were more than two



THE EADS JETTIES, SOUTH PASS



THE BROAD RIVER NEAR MEMPHIS

months behind, with no relief in sight. Yet the men themselves were so confident of success that hardly an employee left the work when the trouble was explained to them. In 1878 yellow fever broke out in camp, and sent the force scurrying in all directions. Operations were for several months entirely suspended, and some of the most valued men on the work were lost through this disease. In spite of such handicaps, however, the progress was fairly steady. To assist in scouring, a big dredge was procured for the bar at the mouth of the Pass, and month after month saw the channel there improve. The most difficult work was that of increasing the height of the jetties by new mattresses, as they sunk beneath the water. Storms often destroyed many of the upper mats, which were not yet concreted.

In 1877, to still further narrow the channel, transverse wing-dams were set out from the jetties into the channel, narrowing it to about 650 feet. By December of that year there were 22 feet over the shoals at the head and over the bar at the mouth, both channels very broad. In 1879, success being apparently in view, Congress passed

an act for the financial relief of Mr. Eads, which permitted the payment of part of the money he believed to be due him, and he was enabled to complete the works. By July, 1879, there was nearly 31 feet of water the entire length of the jetty channel, with a twenty-six-foot channel 200 feet wide; and on July 8, 1879, Captain Brown, the government inspector at the Pass, certified to the War Department that there was a clear channel of 30 feet depth without regard to width, from the Mississippi above the Passes to the Gulf of Mexico. That was the maximum demand of the law.

By the requirements of his terms of his contract, Captain Eads was compelled to continue in charge of South Pass, keeping the jetties in repair, and for twenty years taking whatever means might be necessary to maintain the thirty-foot channel. This task, which has of course been the complete maintenance of the Mississippi mouth almost to the present day, called for no more than the restoration of jetties damaged by hurricanes, the occasional replacing of wing-dams, gradual extension at the ends as the bar has advanced, and the

continual use of dredges over the bar to preserve the depth beyond the end of the piers. For all this he was made the allowance provided by law, which was continued to his estate after his death, and on June 6, 1900, Congress appropriated the last money to complete the Eads contract: $500,000, which had been retained by the nation as a guarantee for the work, and on which the estate had been collecting interest; and $200,000 to buy the plant with which they had been working. At the same time an annual appropriation of $100,000 to maintain South Pass channel was established.

In the years of the Eads control, and down to to-day, the thirty-foot channel has frequently been briefly interrupted; but there has been maintained depth enough at all times to allow vessels drawing from 26 to 28 feet to enter and leave the river, and those depths are now carried regularly out of New Orleans. The channel is safe and reliable, and while careful pilotage is required in the whole length of the Pass, which has shoaled in mid length to equal the cross section of discharge, delays at the Pass are un-

known. For all practical purposes New Orleans has had an unrestricted outlet to the sea.

But the prophecy of Eads has been fulfilled more speedily than he could have expected. The fast increasing traffic out of the Mississippi, and the rapid increase in draft of ocean steamers, has already rendered a narrow thirty-foot channel insufficient for the needs of the great port of the Centre. For years before the Eads charge was taken over by the government, there was a demand for a larger outlet. Southwest Pass, which Eads himself had selected as the only proper outlet and on which he had wished to try his hand, is after all to be the real mouth. The $8,000,000 which we have paid to Eads and his estate represents our tuition in jetty building and the premium we have paid on the open channel for thirty years. We might have saved most of it had we followed the sensible old engineer in the first place. For in 1899 Congress authorized, at a cost of $20,000, a survey to determine the cost of opening Southwest Pass by jetties to give a channel 35 feet deep and 3000 feet wide; and in 1902 an appropriation of $750,000 and a con-

tinuing contract for $2,750,000 were authorized to enable the government engineers to begin their construction.

These works were let out by contract to a single great firm, for whom there has been no hindrance, but only eager coöperation. They have been built in the main along the Eads lines, with his type of mattress, enlarged but only slightly modified, and with the alternate layers of stone and the concrete crown. The new jetties are of great size, the foundation mats being 150 feet wide. They extend, the one on the north nearly five miles, that on the south about six miles into the Gulf and across the bar. At their outer extremity they are about 3000 feet apart; but instead of following the Eads plan of having them parallel, they have been designed with the south jetty beginning at a distance from the river, and approaching it in funnel-like shape, the triangle thus formed to the south of the channel being filled in by dredging from the channel. The purpose of this is to give the jetty a heavy support from southeasterly gales, which here reach hurricane force. The new jetties have been built

with great speed. Having the advantage of Eads's experience, and modern science, and the hearty and active coöperation of the government, the contractors have had little or no delay, and have had ample funds. The Southwest Pass channel will be opened to traffic at the full depth of 35 feet before this book is printed.

Southwest Pass is the natural and final outlet of the Mississippi. If it is ever necessary to do more than is done now toward deepening it, that can be accomplished by lessening the flow in other outlets. But the mouth of this Pass stands in deep water, and is scoured by a strong littoral current setting to the westward; there is no shore under the lee of the Pass to found a new bar or obstruction, and it seems not unlikely that the present works will remain ample for several score years at least, to provide for the enormous commerce which the Mississippi will send this way. The total cost of all the Passes to the present time is approximately $15,500,000.

CHAPTER VII

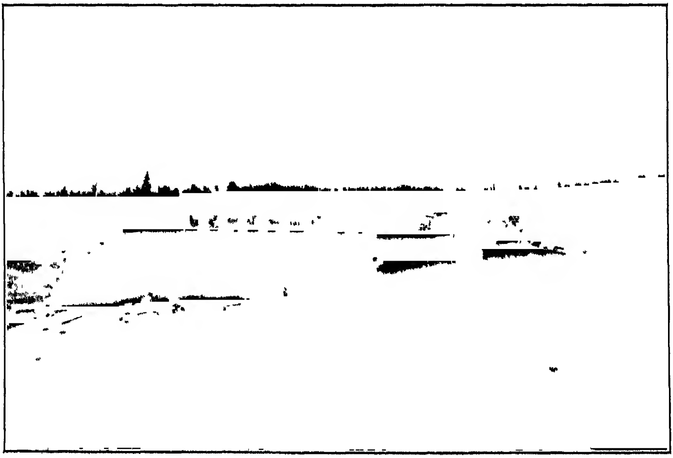
THE UPPER MISSISSIPPI

IT is upon the Upper Mississippi and one of its principal tributaries that one finds carried out, to the highest stage America has yet attained, development by the conservation of the water supply and the forests, together with a proper appreciation of the water power. The upper Mississippi heads in a level plateau, rock-rimmed, and well supplied with lakes and with large swamps. This northern half of Minnesota was originally well covered with pine forests, and enormous areas of forest still persist there, much of it young growth and much held by the state as reserve. The problems which confront the engineer there are to provide a larger storage capacity for the lakes and ponds, to drain the swamps and to straighten and deepen the river between the numerous falls and rapids over which it plunges between Itasca and St. Anthony's, in the first five hundred miles of its course. Below St. Anthony's it has special

problems which we will consider later. To the present time there has been no attempt to develop navigation above St. Anthony's, though, as all the reservoir region is now known to be underlaid with low grade iron ore, which must come south to Illinois and Missouri for smelting, there is no doubt that that channel will some day reach a high stage of development.

The development of the upper river, and the conservation of its waters, begins at its extreme head, in the establishment of a perpetual forest reserve about Lakes Itasca, Elk, and Hernando de Soto, the latter two bodies being within the rim of the ultimate source, and the former furnishing the first definite stream of the Mississippi. About 15,000 acres of primeval pine forest is now included in the Itasca State Park, the land having been turned over to the Minnesota government. In the end it will doubtless be much enlarged, and many of the new forest reserves will be established on the reserved territory of the upper river. This forestation of the sources guarantees the preservation of the ultimate ponds of the river, with their waters oozing throughout

THE MISSISSIPPI AT BEMIDJI



POKEGAMA DAM. THE REGULATING GATE OF THE MISSISSIPPI RESERVOIRS, UPPER MISSISSIPPI

the low season out of the sheltering forest cover. To add to the storage maintained in this way and to check the heavy spring floods, the government has established a chain of reservoirs along the stream, in Winnibigoshish, Cass, Leech, Pine, Sandy, and Pokegama lakes. Each of these being closed at its outlet by means of a beartrap leaf set in a permanent concrete dam, the level of the water has been raised, and a total storage capacity of two million acre feet — about 90 billion cubic feet — obtained. As the river falls below a certain stage, the beartraps are lowered one after another, and the flow is allowed to escape, preserving a navigable depth below St. Paul, and influencing the river appreciably to the entrance of Lake Pepin, about 500 miles below the lowest reservoir. This reservoir system, on which progress is now halted, is not complete, and will not be until a large proportion of the remaining ponds and lakes are similarly treated either by the federal government or by the state or by private individuals. Had a comprehensive system of conservation been employed in the beginning, when the title to all the land along the river was

still in the government, the reservoirs should all have been placed as near as possible to the ultimate source, in order that the largest number of waterfalls might have been affected by the flow from them. Then by the development of these water powers and the electric transmission of the power to the nearest manufacturing centres, a possibility which could not have been foreseen when the reservoirs were established, there would have been provided a definite revenue for the government to repay the original cost. As it is, most of these dam sites, beginning a few miles below Itasca and extending to St. Anthony's Falls, have been alienated in perpetuity without recompense or any qualifying clause, except that in each the government may build and operate a lock when it shall extend navigation to these waters; and that in each dam there must be a log sluice and a fish way. It is not yet settled to what extent the government can go in the direction of electrical development; but there remains open the solution found by Wisconsin for conserving the Wisconsin River, which lies wholly within that state, and which is described later.

Eventually, either under some power from the general government or under the direction of the state, the available ponds will be conserved for the benefit both of mill-owners and of navigation. The result, as far as we have gone now, is to increase the navigable low-water channel at St. Paul a foot in depth. The ultimate result must be to multiply the storage capacity by about four or five times, to increase the period during which the reservoirs are drawn upon, and to add at least a foot and probably eighteen inches more to the low-water channel depth.

All this, of course, means electrical power development, and the employment of that power in electric smelting of the ores hidden beneath the reservoirs and under the surrounding lands; in paper-making; in milling the northwestern wheat; in manufacturing various articles from the forest growth; and in electro-chemical enterprises, which will create a greater traffic for the upper river itself. No careful estimate has yet been made of the power which lies in this stream, and there is as yet no commercial development to make use of it. There is used at Minneapolis

to-day, at the lowest falls, 43,000 horse-power. Between the head of St. Anthony's Falls and St. Cloud there is at least 100,000 horse-power; and it is probable that with the reservoirs established there will be in the long, steep fall from Itasca to St. Cloud at least another 100,000. With the development of that will come the final establishment of barge navigation, to or nearly to the source, by means of the same dams which develop the power and by stone locks beside them. Open channel work, the clearing away of permanent obstructions and of bars, will also be a feature of the work.

The greatest obstacle to navigation between the upper and the middle rivers is the stretch of swift water beginning at the mouth of the Minnesota River, halfway between St. Paul and Minneapolis, and extending upstream above the head of St. Anthony's Falls. No attempt has yet been made to pass the falls themselves, though it ultimately will be done probably by an abrupt dam replacing the falls, and high enough to drown out the rapids, and by a lock and short canal for steamboats. Below the falls the federal govern-

ment has built two locks and dams, in an effort to establish five-foot navigation; but as two feet is all that can be carried as yet up to the lowest dam, there has been no haste in finishing them. It is probable that when the electrical development comes on, a larger dam drowning out both of these will be built to concentrate the power. Certainly a five-foot channel can and must be provided eventually for carrying in coal, for carrying out flour from the wonderful mills of Minneapolis, and for carrying out either ore to the smelter or manufactured iron products from the fabulous and untouched iron beds of western and central Minnesota.

The Minnesota River, formerly called the St. Peter, which enters the Mississippi above St. Paul, is one of its chief tributaries in importance, a prairie stream flowing through what was originally the main valley of the Mississippi. Before the fall of the waters or the shifting of the ground levels stopped such a flow, the waters of Lake Winnipeg and its allies came down through Red River of the North and flowed south through this Minnesota River and on down the Missis-

sippi. The divide between the two systems now is hardly appreciable, and in time will be covered by the establishment of reservoirs at the sources of both. The Minnesota is capable of considerable storage development, adding to the conservation of the flood waters of the river.

From the Minnesota down, navigation is an actual fact. The work has been done to establish a shallow but "open" channel. The aim has been to close all secondary channels and concentrate the water in one; to remove all obstructing rock reefs, and as far as possible the bars; to keep the new bars dredged; to provide ice harbors and shelters, as well as local harbors for towns; to riprap threatened banks; and to provide artificial channels through the two principal obstructions of the stream, the Des Moines and Rock Island rapids.

Des Moines rapids extends for about twelve miles upstream from Keokuk, Iowa, in which distance the river falls more than twenty feet. This rapid is impassable at low stages, and in early days absolutely prevented the upstream passage of steamboats except on liberal water. At the close

of the Civil War the government engineers took charge, and, aided by liberal appropriations, began the construction of a canal about the rapids, with a series of three locks of about eight feet drop each, to pass steamboats of a size up to 350 by 75 feet, and drawing five feet. This canal and the accompanying locks were completed about 1880, at a cost a little less than $6,000,000.

The Rock Island rapids, opposite the city of that name, are less extensive than those at Keokuk, but equally impassable. At the same time that work began at the Des Moines rapids, operations were begun at Rock Island on an open cut through the rock. This cut was made chiefly by means of stone chisels, working in grooves in floats. This work was extremely difficult and expensive, as high as $18 a cubic yard being paid for the removal of some of the rock. The work was prosecuted under a long series of appropriations, and not completed until after the Des Moines canal locks were opened. The straightaway channel, 300 feet wide, was later deepened to give a depth of four and one half feet below ordinary low water.

This work, and that at Des Moines rapids, is, however, of a makeshift character, designed entirely for the purpose of providing navigation, and taking no other account of the value of the running water. Already steps are under way to replace it by more complete development. A private corporation has been given the privilege of drowning out the Des Moines rapids and of developing the power, and even if this concern fails to do the work, it has become evident that in time it will be done there and at Rock Island as well.

The project for Des Moines consists in the erection of a dam 35 feet high, flooding the rapids, and extending diagonally across the stream from Keokuk to the Illinois shore at a point some distance upstream. The three locks and the long canal now held by the government will also be flooded out, and deep water will exist at all stages for a considerable distance above the head of the canal at Montrose. In place of the three locks a single great lock will be placed beside the dam, and navigation will be facilitated by the substitution of quick and open movement for the slow canal passage. The water power at Keokuk will

vary in amount with the stage of the water, being greatest at mid stages, less at low water, and least in floods; but the continued increase of reservoiring on the Wisconsin, the Chippewa, the St. Croix, the Minnesota, and the Upper Mississippi, which will be steadily carried on, will tend to regulate this and make the medium flow a standard, developing something in excess of 150,000 horsepower. The dam, locks, and electric plant will cost about $10,000,000.

With the work at the two rapids and the regularizing improvements, a reliable channel, four feet six inches deep at low water, has been provided from St. Paul down to the mouth of the Missouri.

Below the Des Moines rapids and canal the upper river comes under the domination of the Missouri, a river less in volume of water than the Mississippi, but extremely full of suspended earthy matter, brought down chiefly from its upper tributaries. From this point to Cairo, or rather to Commerce, the river is difficult to manage, and presents problems differing from those met in the clear water above and from those in the rockless

river below. The difficulty met with in maintaining an eight-foot channel there is increased by the new necessity of providing 14 feet through part of the stretch, to accommodate the "Lakes-to-the-Gulf" deep waterway, which is to enter from the Illinois just above the Missouri. This is to be accomplished by erecting a dam at Alton, below the Illinois and above the Missouri, which will deepen the Mississippi above to 14 feet at low water, and will keep out from it the silt problem of the Missouri, always a complication when the Missouri is the higher. From this dam a canal 14 feet deep will extend down the Illinois shore to a point near St. Louis, where it will again enter the Mississippi. St. Louis harbor is already deepened and contracted, and from this point down to Commerce rock removal and the methods of contraction and revetment combined will be sufficient to obtain a deep waterway. At present this part of the river is in a neglected condition, the money spent below Cairo and that above St. Louis not having been paralleled in this stretch which connects those two regions. Ostensibly an eight-foot channel is maintained by dredging, but prac-

tically it occasionally shoals up to five feet or less over critical bars.

The Upper Mississippi has four principal tributaries, of which two, the Missouri and the Illinois, are worthy of treatment in separate chapters. The other two are the Minnesota and the Wisconsin; and the St. Croix and the Chippewa might be added to them.

The Wisconsin is the only stream in America for which a complete and definite system of working-out has been adopted, which includes the storage of water and its effective use for power. The river was long worked over by the federal authorities, who employed the usual means of contraction, deflecting dikes, and dredging to maintain a channel; and in this were the more persistent because the Wisconsin approaches the Fox at Portage, and a canal there connected Lake Michigan with the Mississippi by the route over which Marquette first came to the West. As the extensive forests of the upper country were demolished, however, the Wisconsin, always a river hard to manage, became filled with sand-bars to an extent which precluded successful develop-

ment; and its waters became hard to control, extremely heavy floods and long droughts alternating with each other. Accordingly the federal authorities abandoned the stream and pronounced it unnavigable.

But the interest of the state in the stream was due to another element. This river furnishes, with the Fox, the principal power on which Wisconsin depends for her increasing manufactures. The state contains no mineral fuel. It was essential to continued prosperity that the river be reservoired, in order to conserve the flood supply for low season. The state forester had already selected the headwaters of the Wisconsin as the location for a forest reserve of about three million acres, of which about one tenth is already acquired and in trees. In 1907 there was passed a bill allowing the mill-owners along this stream to incorporate an improvement corporation. This corporation was given power to enter upon all the streams and ponds at the headwaters, in and out of the forest reserve, and to dam them for the purpose of impounding water to preserve the power. But the forester was given authority to

employ engineers at their expense, and to determine exactly how high the water in each pond might be raised, to mark that point with stone monuments, and thereafter to have control over the storage and the use of the water. The state railway commission was given authority to employ engineers, and to survey and determine the exact power previously obtained at every dam site, the area of its watershed, the amount of pondage, and the flow every week of the year. When the storage system has been completed, the commission will make another survey, and determine the amount to which every power is benefited. The corporation is allowed to issue stock to pay the cost of the improvements, and an assessment is laid upon betterment to pay the cost of the state supervision and six per cent dividends on the stock. This tax is assessed by the railway commissioners each year, according to betterment. There are provisions against the establishment of a monopoly, and the state retains the right to buy out the corporation at a fixed valuation.

Under the operation of this wise law, the forests of Wisconsin will furnish yearly a larger

amount of material for the use of her factories. The water stored under the forest cover and in the ponds will furnish a maximum of power to turn the wheels; and the stream itself, protected from sand wash by the forests, settled in the ponds, and free from logs and other obstructions, will again become a navigable waterway not only up to Kilbourne, where vessels were formerly halted, but for many miles farther through the heart of the state. The development of the navigable channel will be almost an automatic affair, with the exception of the construction of locks at the dams; and the Mississippi itself will be largely benefited by the additional steady low-water flow which will be contributed to it at Prairie du Chien.

Our financial account with the main stream of the Mississippi above Cairo, up to June 30, 1906, is as follows:—

To and including 1892.	Des Moines Rapids, canal, and lock,	$5,345,450.00
	Lake Pepin,	60,000.00
	Meeker's Island,	25,000.00
	St. Paul to Des Moines Rapids,	2,833,100.00
	Rock Island Rapids,	1,166,000.00
(In 1852.)	Rock Island and Des Moines Rapids,	100,000.00
	Des Moines Rapids to the Ohio,	6,001,000.00
	Minneapolis to the Missouri (1892),	600,000.00

	Missouri to the Ohio (1892),	525,000.00
	Snags (1870–1892),	507,000.00
	St. Louis harbor,	182,000.00
1893, March 3.	Ohio to Missouri,	658,333.33
	Missouri to Minneapolis,	866,666.67
1894, Aug. 13.	St. Paul to Minneapolis, Lock and Dam 2,	51,000.00
Aug. 18.	Ohio to Missouri,	758,333.33
	Missouri to Minneapolis,	866,666.67
1895, March 2.	Ohio to Missouri (of which $150,000 for trying movable jetties),	758,333.33
	Missouri to Minneapolis (many small specifications),	866,666.67
1896, June 3.	St. Paul to Minneapolis,	100,000.00
	St. Paul to the Missouri,	200,000.00
	Missouri to Ohio, (Continuing contract for $5,000,-025, and order for nine-foot channel below St. Louis.)	275,000.00
1897, June 4.	Ohio to Missouri,	673,333.33
	Missouri to Minneapolis,	826,666.67
	To prevent Cache River cut-off,	100,000.00
1897, July 19.	Ohio to Missouri,	325,000.00
	Missouri to St. Paul,	200,000.00
1898, July 1.	Ohio to Missouri,	673,333.33
	Missouri to St. Paul,	826,666.67
1899, March 3.	Ohio to Missouri,	673,833.33
	Missouri to St. Paul,	826,666.67
	St. Paul to Minneapolis (dam),	150,000.00
1900, June 6.	St. Paul to Minneapolis,	185,000.00
	Ohio to St. Paul,	250,000.00
1902, March 3.	St. Paul to Minneapolis, (Secretary of Treasury authorized to pay balance of a continuing contract authorized in 1899.)	157,000.00
	Missouri to St. Paul, (Three-year continuing contract, $1,200,000.)	400,000.00
1902, June 13.	Ohio to Missouri, (Continuing contract, $1,950,000.)	150,000.00
1902, June 28.	St. Paul to Minneapolis,	250,000.00

1903, March 3.	St. Paul to Minneapolis,	223,579.33
	Ohio to Missouri (continuing contract),	650,000.00
	St. Paul to Missouri (continuing contract),	400,000.00
1904, April 28.	Ohio to Missouri (continuing contract),	650,000.00
	St. Paul to Missouri (continuing contract),	400,000.00
1905, March 3.	Moline harbor,	100,000.00
	(Dredging ordered below Missouri, engineers may use balance on hand.)	
1905, March 3. S. C. bill,	Mouth of Ohio to the Missouri,	650,000.00
	Missouri to St. Paul,	400,000.00
1906, June 30.	Missouri to St. Paul,	300,000.00
	Moline harbor,	150,000.00
1907.	St. Paul to Minneapolis, dams 1 and 2,	30,000.00
		$33,391,779.33
1872–1892.	Preserving St. Anthony's Falls,	615,000.00

RESERVOIRS.

1879–1892.		814,000.00
1894, Aug. 13.		51,000.00
1896, June 3.		80,000.00
1899, March 3.	Winnibigoshish reservoir,	210,000.00
1902, June 13.	Leech Lake reservoir,	250,000.00
1905, March 3.	Pine River dam and other purposes,	160,000.00
	Care of river above Falls,	133,000.00
1874–1892.		$35,704,779.33

CHAPTER VIII

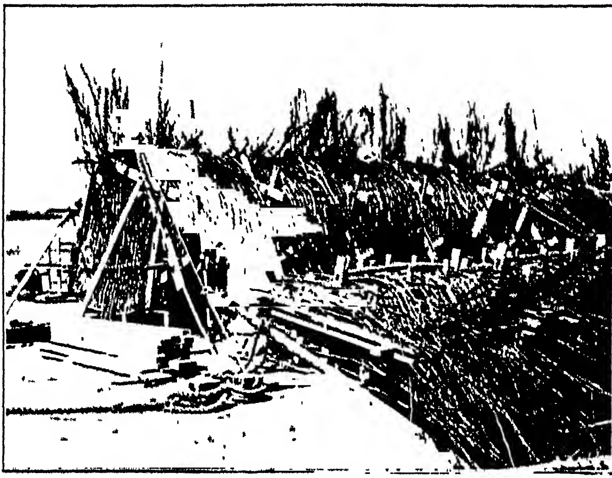
THE MISSOURI

OF all the branches of the Mississippi system, that one which offers the greatest variety of problems for the engineers to solve is the Missouri; and this by reason of its uncertain water supply, its burden of silt eroded from its upper tributaries, the friable nature of its lower bed, and the fact that its waters are in demand not only for the usual purposes of power and navigation, but, in addition, for irrigation. Yet in proportion as it offers large problems, so it contains the promise of large reward in achievement. When the Missouri system shall have been developed to its fullest extent, a large portion of semi-arid North America not now useful for human habitation will have been transformed into a garden of plenty.

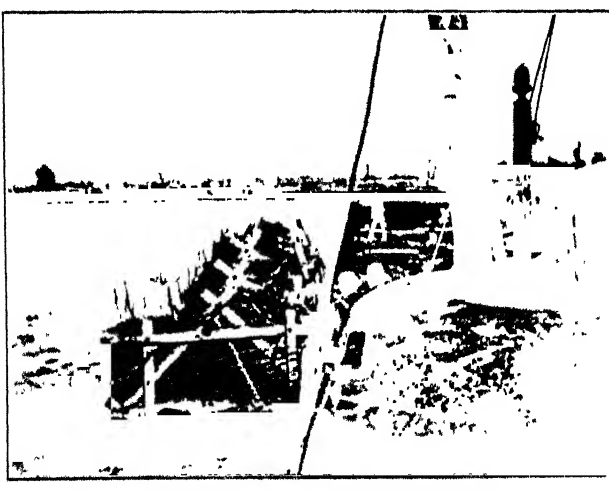
The Missouri has its rise in the union of three rivers in the mountains of southern Montana, and becomes almost at once navigable. It continues

useful for steamboats for several hundred miles, and then plunges down through a rocky course over falls aggregating 512 feet, where it creates at low water a power of about 500,000 horse, some of which is already developed. Below Great Falls it again becomes theoretically navigable, Fort Benton having been for many years head of the steamboat channel. From there across the arid Bad Lands of North Dakota, down through the heart of both Dakotas, near the richest wheat lands in America, between the fertile corn lands of Nebraska and Iowa, of Kansas and Missouri, it continues to maintain a channel capable of development by ordinary channel methods above Sioux City to a depth of three feet, and below Sioux City to six feet under present conditions, both channels being capable of still higher development when the ultimate schemes at headwaters shall have been carried out.

The Missouri is a river with a bad reputation, especially for shifting its bed. During the thousand miles immediately below Fort Benton, it flows largely through rocky regions or through a land where it cannot widely change its chan-



A GROIN TO PREVENT UNDERSCOUR



SINKING A GROIN, MISSOURI RIVER

nel. After passing Sioux City, however, it flows, like the Lower Mississippi, in a hill-compelled major bed, in which is a minor bed of its own establishment, bounded only by sand and soft alluvion, except where the river has driven back against its bluffs. It is a river of swift current, and cuts and tears its banks with more violence than does the larger river downstream. It is, however, not deep, and the measures for its control need not be as costly as those for the Lower Mississippi.

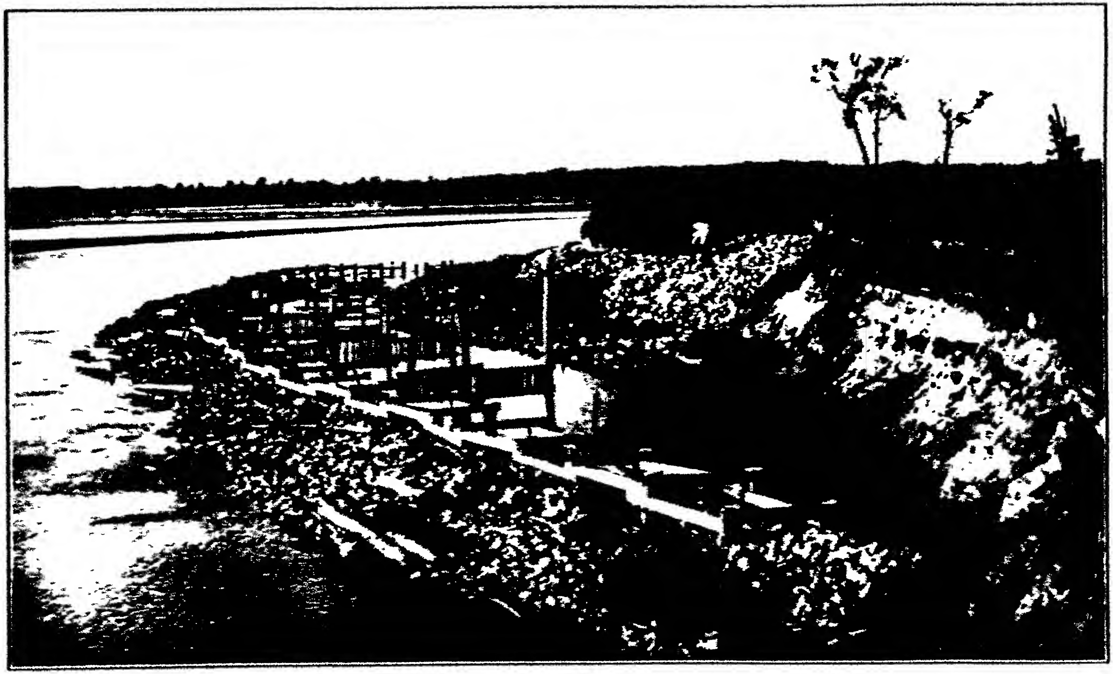
The story of the development of the Missouri is soon told, though it is a story which should be more widely known. In the early days of steamboat traffic, when the Missouri was carrying its share of the great rush to the plains and the gold fields, the channel was not only shifty, but snag-infested. Steamboats ran only by daylight. The government kept snagboats at work in the channel, but in spite of their efforts three hundred steamboats were lost in the river, of which almost all were snagged. It was not until 1884, four years after the Mississippi River Commission had begun to manifest its usefulness, that

Congress created the Missouri River Commission, and gave it charge of the stream. At first this body had charge of all the Missouri, and at once began a comprehensive survey; but later the plan followed on the Mississippi was adopted, and the river above Sioux City was taken from the commission's charge and given into the hands of the individual engineer officers. Control works on the Missouri necessarily were of the type described on the Lower Mississippi,—that is to say, they were entirely local in their character and had no influence and no purpose toward influence upon the general régime of the river.

A survey of the stream made by the Missouri River Commission demonstrated that, with its existing flow, it was perfectly suitable to control for navigation by the methods of revetment and contraction; that owing to its nature such revetment, to be of value, must begin at a fixed point high upstream and continue thence to the mouth in an unbroken system, so that each bend might deliver a current in a definite line into the bend next below and opposite. The history of the

Missouri River Commission, from that time to its extinction in 1902, is the story of the continual advocacy of that excellent plan, and of an attempt to carry it out, handicapped by the methods of governmental control which have heretofore made almost useless all our river work. The commission, having its plans made up, reported to Congress in favor of beginning at Sioux City, and from there down maintaining a systematic work; but compromised on beginning at Kansas City. It was not, however, for several years allowed to do this, but was by specific direction required to spend its money in revetment at certain points, chiefly to protect railway embankments and the approaches to railway bridges. When, for a short series of years, it was allowed to begin at Kansas City and work downstream, it was given short appropriations, and was still required to maintain an expensive plant to carry on the railway protection; so that of nearly $8,000,000 which was all told appropriated for the commission, little more than $3,000,000 was allowed for systematic work in eighteen years, including the cost of plant and maintenance.

Nevertheless, with this, amazing results were accomplished. The problem of revetment, in which at first woven brush mats were used, proved easy to solve with light fascine mattresses, similar to, but smaller than, those used on the Mississippi. A bend in the Missouri properly faced with fascine revetment and stone, with the bend above it similarly held to insure direction, is safe against any changes for a long term of years, and may be retained in that position indefinitely. Unfortunately continuous fascine revetment, even here where the mats needed to be but forty feet wide, was more costly than the commission could provide for, though it could sometimes be installed for $5000 a mile. As a result the commission compromised on a development of its own called a "bankhead." This bankhead is an isolated revetment, made in the form of an arc with the convex side toward the river, the slopes being protected by the existing bank, and supposedly of a curvature which will deflect the swiftest current without injury. The plan was to place these bankheads at sufficiently frequent intervals along the concave shores to establish salient



A BANKHEAD REVETMENT, MISSOURI RIVER

points and hold the bank against erosion, the theory being that, as the bank between them was eaten out, eddies were established in which the river had not the power to eat to any destructive distance.

In theory the bankhead works well. In practice, on such a stream as the Missouri, it requires to be set so close to its fellow, and is so liable even then to injury, that it is not a practicable permanent solution; and but for lack of money it would not have been adopted there.

Supplementary to the bankheads, many forms of dikes were used to close secondary channels and to contract the stream at low water into a navigable bed. On no other of our waters was the ingenuity of our engineers so taxed as here. Many forms of small dike construction, and such oddities as gabions, and burrs — woven cages of brush filled with rock and sunk to form out-footing for bankheads and foundation for sand-bars — were worked out and built in large numbers. The problem was one of getting the most work done with the least expenditure.

The chief difficulty encountered in the long

reach of river, nearly 500 miles, from Kansas City to St. Louis, was at the mouth of the Osage River, where the addition of a heavy sand-bearer from the right bank had always created shifting bars and kept the channel intricate and shoal. The commission not only undertook the management of the Osage by means suggested by the elder Haupt for the Ohio, — that is, alternate open sections and narrow canals, shaped by training dikes, — but made a new mouth for the river into the Missouri, and revetted heavily opposite to it in both directions to insure permanency. The result was most happy, so that with three years of fair appropriations the engineers were able to clear a five-foot channel and maintain it through this reach; and by the end of 1900 they were able to assure boatmen a five-foot channel at extreme low water from the mouth of the Missouri up to Jefferson City, a distance of more than 250 miles.

When Congress decided to abandon the Missouri in 1902, because there was then no commerce on the river, the question of the control of the existing stream had been solved. Up above Sioux

City training dikes had been erected, snagboats and rockboats had removed obstructions, and fair channels for three-foot navigation had in many places been established. No attempt had been made on the ultimate control. But in the lower, on the theoretically impossible "Muddy," the river which was supposed to be able to twist any controlling works ever designed into any shape it wished, the commission had established beyond cavil that competent engineers, with ample but not extravagant appropriations, could do whatever they set out to.

Since 1902 nothing has been done beyond occasional snagging on this part of the river; but the channel remains, showing some of the effects of the commission's work, unprotected as it was left. The five-foot channel to Kansas City persists most of the time, and except for snags, navigation is almost as safe there as on the Lower Mississippi.

On the real development of the Missouri, however, we have yet to enter. This mighty stream — for mighty it is, though in volume less than the Ohio or the Upper River — draws many of its trib-

utaries from a region which contains almost no forest cover. This barren land receives some snow in winter, and heavy rains in May and late April. These rains, after melting the snows, erode the land, and run with increasing burdens of suspended matter into the small streams and thence into the larger. Most of the tributaries which come in from North Dakota's western half flow through deep gorges, and through a country broken and irregular from this erosion. It is the silt acquired here and from the Yellowstone which makes the problem of control so heavy lower down.

After the spring rains are off there fall only occasional showers over this arid region, and these showers are so scattered that they are lost in evaporation without reaching the river. The Missouri has a watershed more than double that of the Ohio, but even were its rainfall heavier than it is, the run-off percentage is so low it could not equal the eastern stream in flow. Consequently the Missouri "dreens away," until it becomes in the low months but an insignificant stream in an enormous bed prepared by and for the spring freshets.

In many of these broken ridges of the Missouri

country there are fabulous stores of lignite coal. It crops out in veins sometimes 40 feet in thickness. All along the river, between the water bed and top of the bluffs, are benches of land which with proper water supply would be of very great value for farming. There are no dam sites on the Missouri below Fort Benton, nor on many of the tributaries in North Dakota, available for the purpose of irrigating by gravity. The Government Reclamation Service, however, has come to the adoption of a new plan, establishing "mine-central" stations at these lignite mines, and conveying the electric power there generated to motor pumps at distant stations, by which the water of the Missouri is pumped up to canals on the several benches, sometimes 100 feet above the river. The establishment of these irrigated regions along the stream will itself have a considerable effect upon the soil wash. And as every pumping station has a settling basin, where the burden of silt is extracted from the water, considerable amounts of waste soil will thus be recovered to be returned to the land. But it is impossible that the pumping of large amounts of river water should be allowed

from a navigable stream at low seasons, unless some compensatory measure is adopted. Accordingly the ravines of the Bad Lands and the gorges of the Montana mountains must one by one be dammed, and transformed into storage reservoirs, for which purpose they are as well suited as they are ill fitted to furnish a gravity flow to the higher benches. In the reservoirs thus established in the heart of the Bad Lands will be found, first, a steadying influence on the stream; second, a means of settling and collecting suspended earth; third, a source of supply for irrigation and of power for pumping; fourth, perhaps best of all, a decided influence on the climate, producing by evaporation an added moisture for the air, which will not be without effect upon the surrounding country. Trees will be planted along the river banks; and the added moisture, aided by irrigation, will be used to transform such of the adjacent regions as can be reached by pumping, into farm lands, and much of the rest into forest tracts, thus cutting down to a minor factor the erosion of the soil.

What will be done in North Dakota will be done also in Montana, on the cloudy Yellowstone and

Milk rivers; and on the lower tributaries similar works will be adopted. Additional storage, additional power, and a lessened erosion will result from all these means; and in the end there will be a Missouri which will send down no great June rise,—for that will be checked in the reservoirs,—and which will not go dry in the fall; but in which from the time the ice moves out until it comes again there will be an ample and steady and fairly clear water supply to follow the contracted and revetted channel to the sea.

In addition to this, the reservoiring of the upper branches will increase the existing 600,000 horsepower of the Missouri in Montana probably to 1,000,000, from which should come a revenue sufficient to improve the whole stream. Our present bill to the Missouri is as follows:—

Appropriated for the Commission, lower river .	$7,010,000
Appropriated for whole river, not under Commission	5,091,000
Total spent on Missouri	$12,101,000
To which is added money spent on the Osage and Gasconade	$803,115.79
	$12,904,115.79

CHAPTER IX

THE OHIO, AND CANALIZATION

HAVING traced thus in brief the development of the channel of two of the principal factors of the Mississippi by measures designed to give unobstructed navigation, and having pointed out the way by which the conservation of these streams must come about, we come now to a new set of problems, those which have to do with furnishing a channel in a river too steep in slope for open channel methods, too variable in level for the employment of fixed dams, and by its mountainous head regions furnishing the sudden deluges and sharp flood waves which provide the greatest difficulty in holding the Lower Mississippi levees. We come to the problem of the canalization of rivers, and especially to the development of canalization in a river of violent and sudden fluctuations.

In volume of water, in flood height, in destructive power, and, for the present, in volume of

commerce borne, the Ohio River is easily first of the upper grand divisions of the Mississippi. It is greater than either the Missouri or the Upper Mississippi, and is the source of all the most destructive floods which sweep the valley below Cairo. It is a river of rocky bed and of steep slope in its upper parts, becoming in its lower reaches gentle and full of sand-bars. As has been described in the chapter on hydrology, it is made up chiefly of a large number of swift-running mountain streams, which empty their heavy rain-falls pellmell into the major stream; and while this tendency probably has been considerably increased by the deforestation of the upper watershed, the river has always been and must always be one of sudden accessions and sudden discharges of water.

For such a stream the improvement for navigable purposes must take the direction of reservoir control, in order that a sufficient amount of water may be retained at all stages. The form of this reservoir control, however, may vary widely; and the form to be used on the Ohio has always been a subject of interesting study among engineers.

The river is itself, in a way, made up of a series of inadequate reservoirs, with connecting channels. From the formation of the river by the union of the Allegheny and Monongahela at Pittsburg, down to Cairo, 967 miles, the river falls about 500 feet; of this all but 157 feet is accomplished above Cincinnati, the smaller part in the 515 miles below that city. From Pittsburg to Wheeling the slope is more than a foot to the mile.

The steep descent from Pittsburg to Cincinnati is by no means accomplished with regularity. The river is, instead, a series of natural reservoirs and dams. There are in all 187 pools in which there is more than seven feet of water at lowest stages; and these are separated by riffles, in which the channel is steep and shoal. The pools make up an aggregate of 632.5 miles, or an average of 3.47 miles each. There are on that part of the river which borders the State of Ohio 103 riffles, aggregating 137 miles, in which the river falls 170 feet, or more than a foot to the mile; while there are on the borders of the same state, and between these same riffles, 309 miles of

pools, in which there is but 64 feet fall. At LeTart's Falls the descent is 3.2 feet to the mile, and there are 11 riffles in which it exceeds 2 feet to the mile. On the other hand, a pool extending from eight to fifteen miles below Cincinnati, below Cullom's riffle, has a fall of but 3.5 inches in 7 miles. On the Indiana front these conditions are reproduced, there being 55 riffles exclusive of the Falls of the Ohio at Louisville, with a descent of 80 feet in 134 miles, and 215 miles of pool with but 18.13 feet of fall, or about an inch to the mile. The falls at Louisville descend 23.09 feet in 2.25 miles. The river flows in a rock-compelled bed, between rocky hills. The rock floor of the valley is rarely more than 75 feet below low water level, and is frequently within 25 feet of that line, the average being between 30 and 50 feet. It comes to the surface at many places, but rarely or never forms at this high level a complete barrier across the valley, leaving, even at LeTart's Falls, a narrow chute through which an open channel can be maintained.

During the years since the Civil War our government has steadily continued the improvement

of the existing Ohio River channel, as it had been begun by Shreve, by open-channel methods. These costly, and not entirely satisfactory, operations are still being extended. They constitute, as do the dikes and revetments of the Mississippi, a series of works of regularization, by which it is sought to contract the river to a regular and sufficient channel. For this purpose there are erected many miles of guiding dikes, of the most permanent type, consisting of cribbing and stone work; many dams and dikes behind islands and across chutes; and a large number of ice-harbor and other protective works. Dredges, snagboats, and rock-removing craft have regularly patrolled the river, with the result that in the course of years what water happens at a given time to be in the river flows with practical certainty in a given channel, which is free of obstruction and safe for the navigator up to its limit of depth.

The limit of depth, however, is very slight. Even in the lower reaches the water sometimes measures but twenty inches, and but for the dam and pool system the upper waters would be even more shoal. The river, which sports a depth of

more than 60 feet in February, is but a pitiful rivulet in August. And from this has naturally arisen the proposal for improving the Ohio by means of storage reservoirs. In the end some such system will undoubtedly be instituted on many divisions of the Ohio, as it will on nearly all our rivers. But there are many complications here which render difficult its general use. It is more than fifty years now since it was proposed by Charles Ellet, Jr., that the improvement of the Ohio and the prevention of floods on the lower Mississippi should be brought about by the same means, the establishment of great reservoirs on the upper waters of the Ohio. Mr. Ellet computed that the storage of a large volume of water by means of dams in the valleys of the Monongahela, the Cheat, the Kanawha, the Allegheny, the Youghiogheny, and many other streams would hold up enough to take the dangerous crests off the floods, and at the same time would reserve enough water to give a good depth to navigation during low-water stages.

Herman Haupt, then at the height of his career, quickly answered Ellet's able pamphlet with

another, in which he analyzed the whole scheme and showed its weakness. On the Upper Ohio tributaries the lands which are particularly valuable are those which lie in the bottoms of the valleys; on them practically the whole population was living. These lands would be drowned out by the reservoirs. The reservoirs would need to be immense, because there are often two or three successive floods in a year, and at least one whole flood must be retained for the summer time. If the reservoirs were filled with one flood, and another came, they could not prevent damage; whereas if they were emptied in anticipation and no flood came, they would have no summer aid. Many other obstacles arose in the way of the plan; and as mining has increased, and the mills in the valleys have increased by thousands, the cost of such a plan has advanced enormously since his day.

Instead of it General Haupt put forward two plans, each a modification of it, in which local storage along the Ohio itself was to be used. In his first plan he would have had a partial dam with lock at the foot of every pool, so that water

should be retained in them, and a channel restricted by a low wall, only 300 feet wide, through each riffle. Thus he would have had at low water open channel navigation through the whole stream; and at moderate stages when there was too much fall from pool to canal, the locks would have been used. The dams were to be low to allow for easy spilling.

From this worked out the system which has been actually developed, and which will possibly always be the largest example of slack-watering, or canalization, in this country if not in the world. This is the lock and dam method finally recommended to Congress in 1875 by Majors Weitzel and Merrill, adopted after long debate by that august body, and now being by slow and painful method put into operation. It is the method of slack-watering by means of collapsible dams, by which each of the natural pools is reinforced with a dam at its lower extremity, this dam being equipped with a large lock; the dam standing erect at low water and holding a large pool in reserve for the purpose of maintaining the channel, and being thrown prostrate on the approach of a

flood, so that the progress of the wave may not be hindered. By this means it was at first hoped to obtain a six-foot low-water channel in the Ohio; but later surveys have demonstrated the possibility of increasing this to nine feet, and the dams already in operation are being remodeled, as fast as circumstances will permit, to that new depth. It is possible twelve or fourteen feet may be eventually obtained by the use of additional mountain reservoirs.

Movable dams, or collapsible dams, are of many types; and nearly all types are to be found on American streams. The principal purpose of them all is to provide a barrier for the low-water flow, which either automatically or with a minimum of effort can be removed from the path of high water. The principal types are the "needle dam," of which perhaps our best example is the dam at Louisa on the Big Sandy; the Chanoine wicket dam, which is generally adopted for the Ohio; the A-frame, somewhat used there; and the beartrap, an American invention much used for sluices and weirs, with its modification, the Crittenden drum weir dam. The needle dam consists of

a supporting trestle and a number of timbers, or needles, set upright, adjacent to each other, their feet upon the dam-sill and their shoulders supported by the trestle. The trestle of a needle dam consists of a number of two-legged frames, A-shaped, each set with one leg directly downstream from the other, hinged to the foundation behind the sill so that all can fall together, sidewise, athwart the stream, and lie nested within each other behind the sill. In this position they offer no obstruction whatever to the passage of floods or vessels. They are raised by a chain passing through them all to the windlass on the abutment, and are equipped with proper parts for forming a bridge connecting them when they are upright. The timbers or needles for such a structure are usually four by four inches, and as long as necessary — very commonly twelve feet. Each of these is equipped with an iron ring at its upper end. They are set and removed when occasion arises, either by a derrick carried on a boat and worked from above the dam, or by a derrick run on a tramway on the trestle itself, and are carried on cars to the abutment. The advantage of

the wooden needles, however, is that a flood coming unexpectedly and filling the river to overflowing lifts them from their position and sweeps them clear, automatically relieving the river of obstruction. The needles, being chained, are not lost. With such a dam the flow of water at mid stages is regulated by taking out one or as many needles as may be required; and the dam may be made very tight by placing strips, at extreme low water, on the cracks between needles.

The A-frame dam, the simplest of all these structures, and much in favor in Hungary, consists of nothing but the trestles which supported the needle dam, their upstream surfaces widened, and themselves set so close together that when erected they strike sides, forming a complete dam. They are lowered by a chain, and lie nested athwart stream like the trestles. Such a dam is sometimes used for a regulating weir on the Ohio.

A beartrap dam is an American invention, in which the head of water between the pool above and the stream below is made to control the height of the crest of a long leaf. The dam con-

sists essentially of a triangular prism having the foundation for one side, and to this is hinged two flaps or leaves for the other sides. These form between them a prismatic chamber, which under pressure tends to extend indefinitely in section toward a rectangle. To do this it must lift the crest of the dam, which is the free end of the upstream leaf. The pressure on the inside is furnished by hydrostatic head either from the stream or from a pressure tank, and is controlled by a valve. The dam is simple of operation, and in some modified form is usually employed as a part of the regulating weir or for passing ice and logs, as it requires little effort to open and close it, and it permits an even sheet to go over the top without widely opening the channel. In the drum weir type but a single leaf is employed, and this is lifted or lowered by the pressure of water in a drum or conduit underneath. In either type the dam at high water is collapsed upon the bottom.

The most used type of movable dam, however, is the Chanoine wicket, of which are built the navigable passes and some of the weirs on the Ohio. This dam dates from very ancient times,

but attained its present estate little more than a century ago through the agency of a French engineer. It consists of a series of panels, usually made four feet wide, set edge to edge across the stream, their feet braced against the dam-sill, and their surfaces supported against the pressure of the stream by an inclined prop, to which they are hinged somewhat below their middle point. As originally employed they were intended to stand until a rising flood put upon this larger top half a greater pressure than on the lower portion; whereupon they would topple to a horizontal position and offer little obstruction to the flow. To prevent opening a whole river when the emergency did not require it, smaller wicket gates were set near the top of each panel, which would thus open at the proper time and spill some of the flood. Difficulties in manipulating these toppling wickets, however, brought about the present system of positive operation.

Under this system each wicket in a dam rests against a horse and a prop, hinged together, the horse also hinged to the sill, and the prop extending downward and backward, with its foot

trapped in an iron casting called a "hurter." This hurter, as used on the Ohio, consists of a channeled iron casting, having at the proper point in the channel a ledge for bracing the prop, and a little forward of this a projection so set that if the foot of the prop be dragged forward to this point it is automatically thrown over into a second groove, which runs clear of the bracing ledge to the back of the hurter. Each panel is hinged to the prop, and carries two chains, which may be operated from a boat or may, more properly, be managed from and held fast to a collapsible bridge above the dam resembling a needle-dam trestle. To set such a dam, the attendant raises his bridge, and going out on it draws up the chain leading to the bottom of the first wicket. The panel which is lying on the bottom behind the sill rises in a horizontal position on the horse to which its prop is hinged. As it rises the foot of the prop comes forward in the latching groove of the hurter. When it has passed the latch and dropped to rest, the operator releases that chain, and with a quick pull on the other draws the head of the wicket up, and the foot of it falls against

the sill, where the pressure of the current holds it. Thus panel by panel the dam is set, until the whole stream is checked. For very low water, strips or timbers are set against the cracks between panels.

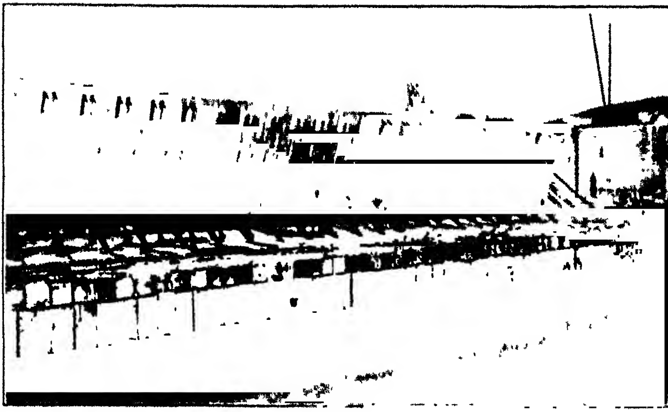
To lower such a dam, or to open enough of it to regulate the flow, the operator draws in on the bottom chain till he tilts the panel up, and chains it in that position. If he wishes to lower it altogether he pulls it still further, the whole comes forward on the horse, the prop drags into the other channel of the hurter, and when released it all falls back behind the sill, prostrate upon the bed of the stream. In some such dams, but not commonly in America, there are used "tripping bars," devices running across the stream through all the hurters in such a way that as they are twisted or pushed along they automatically trip and release, one after another, the several props, and thus lower the dam without the use of the bridge. In large works, however, they do not commonly operate satisfactorily.

In a navigable stream of such magnitude as the Ohio, a collapsible dam is usually made in

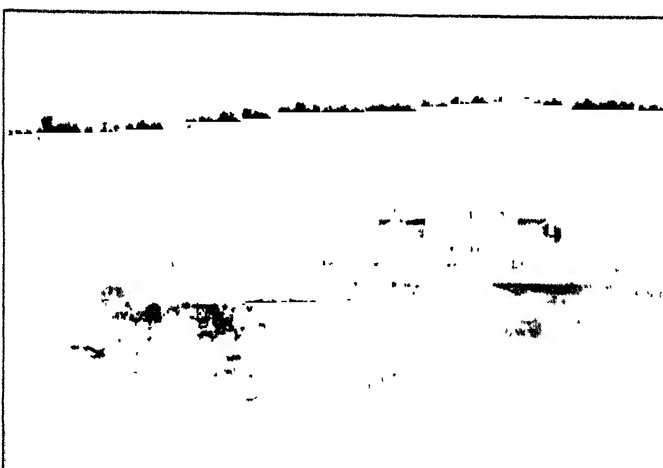
several portions separated by stone abutments; and these several parts are not always of the same mechanical type. The principal parts beside the lock chamber are the pass, the log or ice chute, and the weir. The pass is the navigable high-water channel. In it the longest wickets, resting on the deepest sill, are used in order that the full navigable depth may be obtained. The log and ice chute is frequently a beartrap, as explained before, and is a short section for passing through the dam floating matter which it is injurious to retain. The weir is the regulating part of the dam, built of shorter and therefore more easily manipulated wickets than the pass, and often in several sections, with shorter wickets as the shore is approached. As high water nears, the weir wickets are the first manipulated, to allow an increasing flow through the dam; and as the pool below fills up, it becomes increasingly easy to lower the larger wickets of the pass.

The locks, by which vessels are sent around such dams at low stages, consist of short canals reaching from deep water above to deep water below the obstruction, and in this canal, usually

between concrete walls, a portion is set off as a chamber by gates especially constructed to withstand a head from the upstream side. In old style locks and in many modern ones these gates are in pairs, closing toward each other and meeting to form a sort of arch, upstream, against the pressure. On the Ohio, however, where the locks are 100 feet wide, a new type was invented to make the work possible. These gates are large caissons, sliding in and out from a recess in the walls and extending unbroken across the lock. By conduits underneath the floor of the lock, and by means of gates controlled from the abutment, water can be admitted to the chamber from the upper end and released to the lower. The chamber being full, it has an equal height with the pool above the dam. The upper gate being opened, a vessel passes in. The gate being then closed, the water is allowed to escape to the lower pool, the vessel sinks to that level, and on the lower gate being opened moves out to the lower reach. These locks on the Ohio are the widest at present in operation, but not the longest, being 100 by 600 feet.



CHANOINE WICKETS, OHIO RIVER, DAM NO. 13, SHOWING THE SUPPORTING MECHANISM AND SILL WHILE IN COFFER



DAM AND LOCK ON THE MONONGAHELA

The plan of constructing a deep channel in the Ohio by this means was officially recommended, as I have said, in 1875, by Majors Weitzel and Merrill. Their report accompanying the recommendation was one of the most complete documents of the sort ever filed in the War Department, for they had studied European rivers and their dams with the closest scrutiny. Their recommendation, had it been acted upon, would have given us what we shall long lack, a navigable Ohio; for they proposed that the steep stretch between Wheeling and Pittsburg be taken in hand at once, thirteen locks (the necessary number) be constructed the first year, and thirteen dams the next two years. In four years, or by 1880, the work would have been done, the advantage of large contracts secured, and the stream opened.

Caution, however, carried the day against the project. The Davis Island dam, number 1 of the series, was constructed as an experiment, requiring many years of sluggish effort. Since 1885 it has made a harbor for Pittsburg, and has proven entirely satisfactory, in principle, though it has been several times modified for

experiment and in response to the demands of commerce. In recent years the dams have been ordered, one by one, until now nearly all of the original thirteen have been ordered, six or seven are done, and some are nearly done. Below Wheeling the plan has been adopted of erecting first the dams below the mouths of tributaries, to back pools up into those streams; and below large cities to make harbors, as at Cincinnati. In all, about twenty dams have been authorized or surveyed for. In the course of this work the depth sought has been increased from six feet to nine, the lock-walls have been raised, and the outgrown pass wickets of the old dams have been handed on to make the weirs of the new. In the end, when the Ohio is entirely slack-watered, there will be required between sixty-five and seventy-five of these dams. It was at first estimated that they could be built, including locks, for $750,000 each; but experience has demonstrated that the cost runs well over a million, and it is safe to count on $1,250,000 at each site before they are completely done. This can be considerably reduced if many are built at the

same time. The latest estimate made by the engineers calls for $63,000,000 to complete the project; and it is probable that at the outside $75,000,000 will see the Ohio with its channel cleared and regularized and canalized from Pittsburg to Cairo. Our bill against the main stream of the Ohio to the present time is approximately $22,000,000.

With a long series of dams ordered or in place, and with the nine-foot survey completed, the Inland Waterways Commission has now been called upon to consider a new report on a general reservoir system put forward by Mr. W. O. Leighton, Chief Hydrographer. This plan is an enlargement of Ellet's, by the terms of which storage is to be provided not only above the forks, but on the Cumberland, the Tennessee, and all the smaller streams, in a hundred or more immense reservoirs of such a great capacity that they will hold in emergency a whole year's flow of the river, five thousand billion feet. The same objections to the use of the old reservoir sites still maintain; but their added value is now partly offset by the necessity of

storing and developing all the horse-power of these flood waters, in order to supplement our remaining supplies of coal. The bed of the Ohio is so steep that to try to maintain nine-foot navigation in an open channel above Huntingdon, West Virginia, would be useless. The swift current would be too great for navigation. To that point, even if storage is adopted, dams must be used. But the plan presented to the commission looks to an open river most of the way, the maintenance of a steady flow, and the prevention of disastrous overflows. It will be, of course, eked out with generous tree-planting on the now barren mountain-sides.

This problem involves the development of large water-powers. An additional feature of the Ohio improvement is the problem of the utilization of power at the movable dam sites. When all these dams are raised to the nine-foot stage, there will be at low seasons, and all the year during a steady flow, a great power developable. This will probably, however, not become economically possible until power becomes more valuable than it is to-day.

Yet with the development of the forests of Pennsylvania and West Virginia, and with the establishment of great storage dams, the tendency to drown out these dams and to give them almost no overflow at low water will be decreased. The period during which they stand will be lengthened, and in the end it may become possible to replace them with permanent dams offering continual water-power; or, at least, to develop from these movable dams a power which will be available at least three hundred days in the year.

The Ohio River is not leveed as is the Lower Mississippi, and the flood problem is a serious one, becoming to the mill towns more serious as the wealth of the valley increases. In most places the width to which it can overflow is so slight that there is not, except in the case of big cities, sufficient taxable property endangered to support a levee system. Reservoiring will largely diminish this danger, and save the valley probably several million dollars every year.

Just as it is in itself one of the principal tributaries of the Mississippi, so the Ohio forms the

backbone of a smaller system of rivers, some of which rank well with the largest in Europe. Of these the chief in length and volume are the Tennessee and the Cumberland, which flow into it on parallel courses near its mouth. These are two of a large number of streams draining the Appalachians on the western slope. In common with the other streams of this region, they will in time be improved by forestation on the highlands and by the establishment of reservoirs. They are streams of great water-power possibilities, and when improved completely will furnish navigation from their mouths well up into the mountains in which they have their origin. Work on the improvement of these rivers for the purpose of navigation has been carried on for about forty years, and in that time locks and canals have been established on the Tennessee, around a long series of rapids and shoals through northern Alabama. This improvement limits the size of vessels which can now navigate the stream. The development of water-power has, however, given a new turn to the manner of treating the river, and before many years have elapsed the canal will

be paralleled by a river thoroughly developed by dam and pool for deep and wide vessels. This section of the Tennessee flows through the iron and milling country of northern Alabama, and maintains a heavy traffic. The traffic, however, is small below there because of irregularities in development. When the present plans have been carried out, steamboats drawing five feet can pass up the Tennessee to Chattanooga, and drawing three feet can ascend a considerable distance above Knoxville. Eighteen-inch navigation will eventually extend a long distance above the present head of navigation.

The Cumberland is also being improved, by locks and dams, to a five-foot depth, but by one of the inexplicable mistakes of government is blocked by locks five feet narrower and eight feet shorter than those of the Tennessee, so that boats built for the latter river cannot use it. The Cumberland is now navigable for a considerable distance above Nashville, at fair stages of the river, and will eventually offer an outlet for the coal of the region from Burnside to Jellico. Some of its tributaries, as the Green River, the Rough,

and the Barren, are also improved by locks and dams.

Higher up, the Ohio receives the Kentucky River, on which navigation is provided by a long series of locks and dams, offering an outlet for the coal lands of the interior of the state; the Big Sandy, which with its Tug and Levisa forks is improved with needle dams and locks; the Kanawha and the Little Kanawha, coal-bearing rivers similarly treated; and, at its head, the Monongahela and the Allegheny, both slack-watered streams, and both leading from rich manufacturing and coal producing streams. On its right the Ohio first receives the Beaver River, which is being turned into a canal to connect the Ohio with Lake Erie. Below this, the principal navigable tributary is the slack-watered Muskingum. The White and the Wabash offer inlets into Indiana and Illinois, but though considerable sums have been spent upon them, neither has been systematically taken in hand, and neither is now commercially navigable. Yet on all these rivers the new hydro-electric developments and the new conservation knowledge indicate an early

day of commercial utilization. It is estimated by Mr. Leighton that if the designated reservoirs in the Appalachians be built, the streams tributary to the Ohio in that region will *increase* their commercial horse-power more than 3,000,000 horse, if the reservoired store is used for twelve months, or 6,000,000 if it is drawn on only six months each year.

CHAPTER X

LAKES-TO-THE-GULF

FROM the earliest days of the exploration of the West, from the time of La Salle and Marquette down through the succeeding generations of French and Spanish and English and American explorers, there have never been lacking those who sought to connect by navigable channels the waters flowing into the Gulf of Mexico with those flowing into the St. Lawrence River. It was by a route easily opened that Marquette himself first reached the Mississippi, passing from Green Bay up the Fox River, and by way of a flooded portage into the Wisconsin River, and so down to the site of the modern city of Prairie du Chien. It was by another portage that he returned to the Lakes, coming up the Illinois River to its forks, thence following the Des Plaines to a depression in the hills which has since come to be known as the Chicago Divide, and there camping near a low flooded prairie by

which his boats crossed to the Chicago River and Lake Michigan. By still another route La Salle made at least one of his journeys, crossing from what is now called Sag to the Calumet River, and on another journey he entered the St. Joseph River, and, ascending that to a point near the present city of South Bend, crossed a short portage to the Kankakee, and so descended to the Illinois. A favorite route with some of the *coureurs de bois*, and one which was followed probably by Membré and some of the other early missionaries, was by way of the Brulé River from Lake Superior, and from its headwaters down the St. Croix to the Mississippi; and still another easy route was by the ascent of the St. Louis, and a portage by a series of ponds over to the Upper Mississippi itself near its great bend.

There were as many more easy connections between the two water systems farther east, by way of the Maumee and the Wabash, the Maumee and the Miami, the Cuyahoga and the Muskingum, and easternmost of all by the Beaver and the Grand. Of them all, the most direct, the most natural, and the most promising was, and still is,

that through the Chicago Divide which Marquette commented on, and through which La Salle determined to open a canal for bateaux. This route *par excellence* is referred to now when one speaks of the route "from the Lakes to the Gulf." But in the century during which our waters have been developed, many of the minor routes have been opened by small canals, some of which will a century hence doubtless be large factors in our transportation; and the Beaver-Grand route is now being cut through by a twelve-foot barge canal, to bring Pittsburg in touch with the iron ore traffic of Lake Erie.

To begin at the most northern of all these proposed channels, the route from Duluth to the Upper Mississippi by way of the St. Louis River has several times been surveyed, and estimates have been made of the cost of a six-foot barge canal of the old type. The purpose of this waterway, of course, is to give St. Paul and Minneapolis direct water connection with the Lakes. Minneapolis produces about fifteen million barrels of flour annually, the greater part of which goes east by the Lakes, which are now reached by rail.

The cities are also the gathering depots for an immense amount of wheat which is on its way east; and they are not only heavy consumers of coal, but are distributing depots for coal to the Northwest. In addition, package freight of all sorts moves in large volume between these cities and the Lakes.

A barge canal connecting these points by way of the Upper Mississippi and the St. Louis would require an ascent of nearly 600 feet from Lake Superior to Summit level, and a considerable descent on the other side, accomplished, however, chiefly in the Mississippi. Such a channel would be closed by ice from the 1st of November, or the end of that month at latest, until the middle or end of April. During the remainder of the year it would accomplish a great deal in relieving traffic conditions of the Northwest. Unfortunately the enormous water-power of the St. Louis, which should have been conserved in any development of this route, has passed into corporate hands; and nearly all that of the Upper Mississippi has also been alienated; the drainage problems of northern Minnesota, however, are

large, and could easily be made tributary to such a commercial development.

The route by the Fox and the Wisconsin has always been one to draw the attention and to arouse the imagination. In the early years of Western settlement a private company was incorporated to develop navigation this way by means of a lock and dam system on the Upper and Lower Fox, and a canal connecting the upper part of the stream with the Wisconsin at Portage. After the company had expended considerable sums the general government took over the work, and spent in all something more than $4,000,000 upon it. The result was, as far as river improvement for navigation is concerned, a total failure. This failure was one of method rather than one inherent in the route. In the first place, the rapid deforestation of Wisconsin caused the river which bears that name to become filled with sand swept in from the deforested areas, giving rise to shifting obstructions, which no reasonable amount of dredging could keep cleared away. The deforestation caused the water supply of the stream to become so unreliable that heavy floods

in spring time were followed by almost complete drouth in the summer and fall, in which no steamboat channel even of two-foot depth could be maintained. The canal which connected with the Fox was a small affair, and there was no type of steamboat of such peculiar structure that, being at the same time narrow enough for the canal and shallow enough for the river, it could profitably carry cargo. As a result, the government some years ago abandoned the Wisconsin as a navigable stream, and looked upon the sum therein invested as a total loss. The Lower Fox, however, remains a stream in successful use, and the many dams which cross it furnish some of the greatest water-powers in Wisconsin.

The various connections which the canal-building epoch of the forties and earlier years saw constructed through Indiana and Ohio, notably the Maumee-Wabash-Miami and the Cuyahoga-Muskingum routes, do not properly come up for consideration within a volume upon river control. With the exception of a few short reaches in which the river-bed was used, notably ninety miles of the Lower Muskingum, they were essen-

tially canal construction, presenting no differences or advantages over other long inland canals of their type, — shallow and providing only for small barges carrying about 250 tons each. Each route required something like 600 feet of elevation, making passage long and tedious, and each has been gradually abandoned with the decrease of water transportation in general. With a revival of this mode of transit, each route offers the possibility of ultimately becoming an economical carrier of considerable larger size than at present exists.

The route by way of the Beaver valley, from its confluence with the Ohio just below Pittsburg, and the Mahoning to Niles, and thence by canal through the divide to the Grand River or some one of its branches, has lately come into prominence through the granting of a charter by Congress, under the terms of which a private corporation is constructing the channel and is allowed to charge toll upon it. This corporation has been allowed to do many of the things which the government engineers will ultimately require to do in preparing streams, that is to say, to provide

for storage, and to develop the water-power incidental to their work. For this purpose they may enter upon the route with right of eminent domain, and may construct — and are constructing — a channel in the Beaver by means of locks and dams, not less than 12 feet in depth and 150 in width. A new harbor is to be constructed on the shore of Lake Erie, not far from Ashtabula, and large terminals erected for the transfer of freight. The company has the right to construct a second navigable canal up the Shenango to Sharon in Pennsylvania, and to divert stored flood water from the Allegheny at Franklin, Pennsylvania, for summit level.

The real purpose of this canal is of course to connect Pittsburg with Lake Erie, and to cut still one more charge out of the freight bill on iron ore from the mines to the mills. At the same time it will reduce the coal shipping bill from Pittsburg to the upper lakes. In connection with the Erie Canal and the improved Ohio, it will offer eventually a nine-foot barge route from New York City to St. Louis and New Orleans, and an inland passage of much importance from the

northeastern interior to the gateway to the Panama Canal.

In this regard, however, and in its general usefulness, it is outstripped by the proposed fourteen-foot waterway by way of the Chicago Divide. Chicago stands in a depression in the rocky rim of the Great Lakes, at a point where the waters of Lake Michigan once poured out by what is now the Des Plaines and the Illinois River to the Mississippi. Tilting of the plane or recession of the waters has changed this outlet, but the depression still remains so low that in high water canoes and bateaux have been floated over it, and in making the present cut through it there was in no place any earth encountered more than fifteen feet high above the standard elevation of Lake Michigan. Unlike the other routes suggested, therefore, this one requires elevation by lockage on one side only, coming toward the Lakes, the transfer being one from a summit level at one end to a bottom level at the other. The question of water supply is solved by the fact that the summit is Lake Michigan.

The Chicago Divide is about thirty miles across

from the shores of Lake Michigan to the point where the land drops abruptly away into the valley of the Des Plaines and of the Mississippi. Part of the way, on the lake side, this is made up of clay and of glacial drift; but for a large part it is a clear, soft limestone, easily worked and, when removed, of good marketable quality for concrete, for building, for the manufacture of lime, and for a flux with iron ore. As early as 1817 a canal through the divide was proposed, some years before the federal government had bought the site of the present city from the Indians. And in 1826, before Chicago was more than a tiny collection of hovels, Congress passed a canal bill, providing that alternate sections of public land in a ten-mile strip might be sold by Illinois to pay for the construction through them of the "Illinois and Michigan" canal.

Under this enabling act, which owed its passage to a tie-dissolving ballot by John C. Calhoun, then president of the Senate, Illinois eventually undertook the work, and in 1846–47 completed a small canal, providing for four-foot navigation, from La Salle on the Illinois to the Chicago River

at Bridgeport, about 96 miles. This canal had a summit some distance above Lake Michigan, which must be supplied by pumping. Gradually in succeeding years this little canal was rebuilt and enlarged until it provided for vessels six feet deep and carrying about 250 tons each. In this condition, in the years immediately succeeding the war, it carried an enormous traffic, and was one of the chief elements in building up Chicago and St. Louis, and in solving the early problems of getting to market the grain of the newly opened West. In a single year the canal tolls amounted to more than $300,000. Soon, however, the canal began to find itself unable to compete with the railways, and in the years following 1880, and especially 1890, it has fallen into disuse and disrepair.

Ever since 1871 Chicago has been sending down this old canal a great volume of sewage drawn from the south branch of the river, into which the sewers of most of the city drain. As even this outlet was inadequate and sewage still ran into the lake, Chicago's citizens began, some time before 1890, to agitate for a new canal to

carry away all the sewage and, by preventing contamination of the lake, to reduce the deaths from typhoid, then a terrible scourge in the city. Though it appeared to be the ultimate solution of this matter to build a sewage disposal system, far-sighted business men directed sentiment in such a way that the public voted for and authorized a deep ship and sanitary canal, extending through the rock barrier to the valley of the Des Plaines. This was begun, carried swiftly to completion, and by 1899 offered a channel 162 feet wide in rock and 200 in earth, 24 feet deep at all points, from the Chicago River to a spillway in the valley of the Des Plaines. The work as then completed cost the city about $35,000,000.

From that time to the present Chicago, with the assistance of the entire valley, has labored for government aid to extend this canal as a fourteen-foot ship canal to the Mississippi, and so to New Orleans and the Gulf. Congress has authorized, and the engineers have carried out, surveys showing the cost and practical character of the extension as far as St. Louis, and more recently it has received the approval of President

Roosevelt. It is entirely probable that in the new era of waterway development it will be one of the first projects carried out.

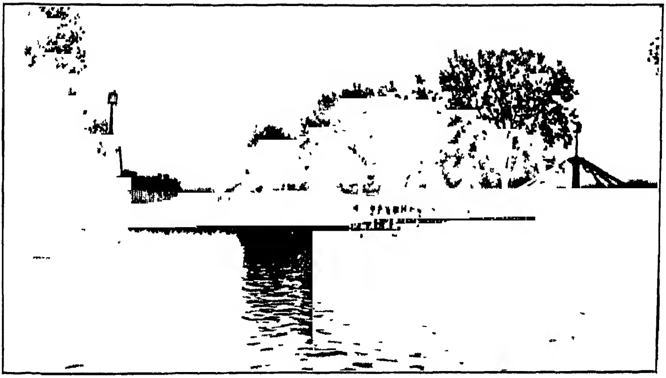
The scheme for this waterway as at first outlined provided for an extension of the canal from its present terminus through the city of Joliet, by canal and locks, to the Des Plaines River in Lake Joliet. Thence it was to follow the bed of the stream, cleared of rocks and deepened by damming, to its confluence with the Fox at Ottawa, and thence to follow the Illinois to the Mississippi. The plan further contemplated, and with this amendment is reported to Congress, a dam across the Mississippi at Alton, just above the Missouri, to deepen that stream to fourteen feet, and for a canal thence around the Missouri mouth, on the Illinois side, about eighteen miles to a point just above the Merchant's Bridge in St. Louis. From there the Mississippi is to be developed to fourteen feet by the methods hereinbefore described.

Since this plan was outlined many changes have been brought about in the general waterway situation, and especially in the relation be-

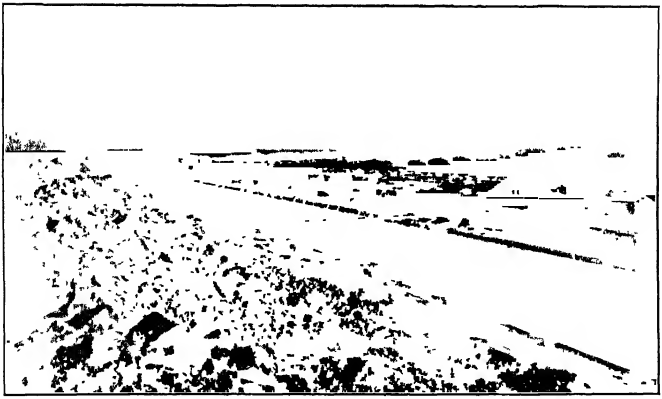
tween waterways and water-powers, which have done much both to retard and to accelerate it. The river into which the Sanitary Canal empties itself is not only very variable, but in summer time extremely shoal, and flows in a steep and rocky bed. The question of water supply solves itself because of the peculiar nature of the Chicago Sanitary Canal, which is primarily for sewage dilution, and which therefore is designed to provide, without interfering with navigation, a flow of 10,000 cubic second feet of water from Lake Michigan. The addition of this amount of water to the Des Plaines gives it enough, even in lowest stages, for the development of fourteen-foot and even eighteen-foot navigation. This navigation must be accomplished in the rocky river, however, by the use of large dams, and a channel in the river-bed cut out of solid rock and forming practically a canal, with short canals around several falls.

From the end of the Sanitary Canal at Lockport to the level of the Illinois River at Utica there is a descent of 147 feet, the greater part of which is accomplished at Joliet, and the rest

of which can be concentrated principally at Marseilles and Utica. In normal conditions the powers at these sites have been hardly worth developing, but with the added flow from the Chicago channel they have become extremely valuable, notably that at the so-called "dam number one" in Joliet, where a variable 700 horse-power was turned into a reliable power of 10,000 horse. Grasping the value of this power too late, — for its development should have been from the first one of the chief objectives of the canal construction, — the authorities of Chicago and those of Illinois are now working together to devise and put into operation some scheme by which they may regain control and develop these powers, using the income derived therefrom to pay off the bonds on the whole investment. The power here is extremely valuable, the manufacturing sites along the way have the double value of water transportation in both directions and the trunk line railways of Chicago reaching everywhere, and it is probable that the waterway, as it develops, will become the site of one of the greatest manufacturing districts in the country.



THE LOCK AT HENRY, ILLINOIS RIVER



CHICAGO SANITARY AND SHIP CANAL

From Chicago to La Salle is a little less than 100 miles. From La Salle to the mouth of the Illinois is more than twice the distance; but in it there is practically no rock to be encountered. The Illinois is a river of gentle slope and of considerable breadth, and retains the contour of its bottom and the stability of its banks better than any other stream of its size and character in the country. Before the construction of the Chicago channel it had been improved by means of gradual appropriations extending over about forty years, by which the state constructed two dams and the federal authorities two dams across it, with a lock 75 by 350 feet at each dam. These dams have been lowered since the Sanitary flow was turned on, and are now probably unnecessary to maintain the seven-foot navigation which the Illinois supports at all stages. The bottom is of such character, however, that it can be easily dredged, and of the total cost which will be represented by the deep waterway when complete, only a small portion is for dredging to fourteen feet from La Salle to Grafton.

Before the Civil War, as the Northwest de-

veloped, there began to be agitation for a waterway connecting the Illinois at La Salle with the Upper Mississippi at Rock Island. At first the plans were for a ship canal seven feet deep and wide enough for upper river steamboats. During the next thirty-five years several surveys were made of this route, by way of Bureau Creek to the summit, and thence by Hickory Creek and Green River to Rock River, and so to the Mississippi. The canal was finally undertaken under the name of the "Illinois and Mississippi," or, as it is more commonly called, the "Hennepin" Canal, and was dragged slowly to completion, the water being admitted to it in 1907, after an expenditure of about $7,000,000. The canal as completed rises abruptly out of the valley of the Illinois, in a series of locks aggregating more than 150 feet, and descends more than 90 feet on the other side. It is but 7 feet deep, and its locks are but 30 feet wide. Though it may in time develop some use as a feeder for the larger waterways, it is built upon lines which were outgrown about the time the first survey was made, forty or fifty years ago.

The total expenditure upon the Chicago Sanitary Canal, the Illinois River, and the Hennepin Canal route to date is as follows:—

Whole cost to date, Illinois and Michigan Canal	$13,000,000
Cost of all Sanitary Canal Work . . .	50,000,000
Illinois River (state and nation) . .	3,000,000
Hennepin Canal	7,500,000
	$73,500,000

The estimated additional cost of the fourteen-foot waterway from Chicago to St. Louis is $30,097,462, of which Illinois has agreed to provide $20,000,000.

CHAPTER XI

THE TRIBUTARIES

ENGROSSED with the story of the engineering development and the prospect of proper conservation of our streams, I have not, up to this point, indicated one of the most vital principles upon which all this river improvement work should be based. That is the standardization of all the channels, according to their capacity and the nature and demand of the traffic which they are to bear. This has been the less necessary in so far as we have been dealing with the main streams, because our projects for these are all based upon an effort to obtain from each river the deepest and widest channel possible. On the tributaries, however, and especially on those which are developed for navigation by other than open channel methods, this standardization becomes of the utmost importance.

Before projects for these rivers are adopted, they should be related to a general plan of im-

provement, which should provide certain standard sizes of channel and of opening through channel obstructions. Thus, on rivers of given width and depth, all the locks should have openings and length of the same standard, so that vessels might ply freely from one to another; and any vessel built for one part of a river could be certain of finding room to pass anything in the lower courses, at least, of the same stream.

Such a standardization requires a thorough survey of all the now navigable or possibly navigable streams, with a view to our new knowledge of the possibilities of stored water and steadied flows, and a survey of the probable types of traffic which will be served by the stream. These rivers should then be designated as Class A, Class B, and so on, each class representing a certain width and depth of channel, each river, perhaps, having different classes of increasing importance as its lower reaches were approached. It should then be certain that a vessel navigating upon the upper reaches of any river would find all the locks below open to her, and that a steamboat which was employed on Class B rivers in Wisconsin in

summer could be sent with positive assurance to some Class B river in Louisiana for the winter. Barges of standard size, then employed for cargo, could be loaded at principal ports, with assurance of carrying cargo unbroken to destination.

As yet no such measure has been taken in our country, and there has not been prepared any complete survey from which the amount of navigable water within this system can be estimated accurately. Several governmental departments having authority have prepared individual estimates; and a more accurate report has been made to the French government by its Minister of Marine. I have, however, compiled a considerable table of these waters from the figures given in the report of the Chief of Engineers for 1902, when a report on all projects was made to Congress, revising this considerably by subsequent reports; and have compared this with a report made to the Secretary of the Treasury some years ago by Mr. A. D. Anderson, and a bulletin published in the Tenth Census, the work of a Mr. Vivian. The guesses of these at times exceed the total length of the river they are considering. In

others, their errors follow upon the heels of Humphreys and Abbot, and in others they are the steamboat-men's easy guesses. I present them in the following table, together with the total appropriations to June, 1906, which have been made for these rivers as far as I have been able to collect the figures, with which I have included the main rivers:—

River.	A	B	C	D	E
Missouri	3127	2915	2378	[illegible]	1
Mississippi	2161	2134	2152 (a)	[illegible]	1 and 2
Ohio	1021	967	965	[illegible]	2 and 1
Red	986	1000	679	2,749,637.00	1
Arkansas	884	771	463	1,947,375.00	1
White	779	300	391	1,188,215.00	2 and 1
Tennessee	759	650	652	6,580,551.00	1 and 2
Cumberland	609	578	609	3,277,000.00	2
Yellowstone	474	300		(b) 10,000.00	
Washita	384	306	300	1,166,954.00	2 and 1
Wabash	365	183	120	820,000.00	2
Osage	303	200	200	687,600.00	2
Bœuf	280	261	151	(c)	1
Minnesota	295	25	37	140,500.00	1 and 2
Sunflower	271	144	100	(d)	1
Illinois	270	225	223	2,346,650.00	2
Hennepin				7,447,995.47	
Yazoo	228	173	240	(d) 1,774,500.00	1
Bartholomew	213	85	138	(c)	1
Black (Ark.)	212	100	250	172,100.00	1
Green and Barren	200	175	227	660,873.20	2
St. Francis	180	285	171 (e)	200,000.00	1
Tallahatchie	175	100	180	(d)	1
Wisconsin	160	62		(f) 3,748,914.93	2
Cache	160	(g)	95	(g)	1
Macon	130	(h)	112	(c)	1
Allegheny	123	180	26	1,781,766.63	2
"			230 (i)		
Deer Creek	116		(j)	(d)	1
Monongahela	110	102	131	5,814,596.13	2
Kentucky	105	261	261	3,051,495.74	2
Kanawha	94		90	4,421,437.00	2
Muskingum	94	96	91	252,800.00	2
Tensas	92	130 (h)	81	(c)	1
Iowa	80				
Current	80	(k)	72	(k)	1
Big Hatchie	75	100	240	35,500.00	1
Rock	64		61	(m)	2

River.	A	B	C	D	E
Black (La.)	61	(n)			
Chippewa	55	57		$161,750.00	1
St. Croix	57	120	52	30,000.00	1
Big Horn	50				
Clinch	50	70	126	(o) 132,500.00	1
Little Red	49	90			
Big Cypress	44	65			
Big Black	35	65		15,000.00	1
Dauchite	33				
Obion			75	27,500.00	1
Forked Deer			29 (p)	36,500.00	1
Galena		10	6	170,102.00	2
Gasconade		6	107	100,500.00	1
Big Sandy		87	26	1,302,020.00	2
Tug Fork		100	58	(q)	2
Levisa Fork		86	88.5	(q)	2
Elk (W. Va.)		45	45	(r)	1
Gauley		27	12	(r)	1
Guyandotte		80	18	21,500.00	1
Licking (Ky.)		90	50	16,000.00	1
Hiwassee		43	35	(o)	1
Holston			60	(o)	1
French Broad		90	72	140,000.00	1
Rough			29.5	105,500.00	2
Little Kanawha			48	378,418.00	2
White (Ind.)		27	13	120,000.00	
Tradewater		22	41	16,500.00	1
Bayou LaFourche		110	105	255,000.00	2 and 1
Bayou Plaquemines		110	30	1,775,000.00	2
Homochitto			60	20,000.00	1
Duck River		67	68	(o)	1
Little Tennessee		13	13	(o)	1
Buckhannon		48	24.5	5,500.00	1
Cheat		90	49	13,000.00	1
Yallabusha		90	63	(d)	
Other Yazoo waters		170	100	(d)	1
Obey River		58			
Caney Fork		92			
Bayou Black		14			
Bayous D'Arbonne and Courtableau		68	68	(c) 233,700.00	1
Little and L'Anguille		123	(e)	(e)	1
Fourche la Fave		44	44		
Petit Jean		45	45		
Little Missouri					
Saline		80		(n)	
	16,283	15,140	12,986.5	$193,055,515.80	
Subtracting major	6,579	6,241	5,718.0	45,305,650 00	
streams leaves minors.	9,704	8.899	7,268.5		

A is Mr. Anderson's estimate, B is Mr. Vivian's, and C is compiled from the reports of the Chief of Engineers. D is the cost of the improvements to date as nearly as it can be compiled from the reports, and E is the method of improvement — 1 being open channel, and 2 slack-water.

The following notes refer to letters in the tables: (a) This includes only the Grand Rapids reach above Minneapolis. Eventually there will probably be 2500

miles navigable. (b) Declared not navigable by Congress after construction of Northern Pacific Railway. (c) All these bayous are lumped together in cost column under Bayou D'Arbonne. (d) Included under Yazoo. (e) This estimate for the St. Francis is based upon a recent report of the Board of Review. The river is sometimes considered navigable for about 289 miles at high water, with two branches, Little and L'Anguille rivers, offering considerably more. (f) This includes the cost of the Fox and Wisconsin improvement, excluding such parts as are only of value at the Lake Michigan end. The Wisconsin is not now navigable. (g) Cache River is included under White of Arkansas. (h) Mr. Vivian puts Tensas and Macon together. (i) This is the Upper Allegheny, on most of which there is no upstream navigation, but it is listed by the War Department as navigable for rafting and floating downstream. (j) This one of the "Other Yazoo waters," listed lower down. The War Department lists the whole Yazoo system at about 800 miles, but accounts for only a part of that. (k) Current is included in Black of Arkansas. (m) A part of the Hennepin route. (n) Mr. Vivian includes the Black of Louisiana with the Washita. (o) The cost of all the minors of the Tennessee has been put together under the Clinch River. (p) 195 miles to Jackson, Tennessee, was formerly included in this, but is not now used. (q) Tug and Levisa are included under Big Sandy. Elk and Gauley are included under Big Kanawha.

This list is necessarily incomplete and imperfect. So, also, is that of the cost of the improvements. There are several items of state expenditure which do not here appear, notably those for the Muskingum ($1,300,000), for the Kentucky ($750,000), and for the Green and Barren ($657,000), the state expenditure on the Illinois (about $1,000,000), and the Chicago Sanitary Canal ($45,000,000), making a total of $241,762,515.80. Many rivers which are slack-watered have indefinite appropriations for maintenance, which are only to be found in the report of the Chief of Engineers year by year, and which in the case of the Muskingum have already footed up to more than $1,000,000. With these, how-

ever, and with many of the smaller annual appropriations for snagging, we are not actually concerned, as they are bills for running expenses rather than for channel development. It is also difficult to draw the line among the bayous of Louisiana, and to determine which of them are properly here to be included and which left out as not properly parts of the system.

In the development of the lesser streams the engineers have followed the same methods that have been used on the larger rivers. The steep mountain streams which flow into the Ohio have required general slack-watering, and those which come down on the south of the Ozarks into the lowlands of Louisiana are now being similarly treated. In connection with this slack-watering, the channel is snagged, rocks are removed, and contraction and training works are erected where needed. Streams which do not need locks and dams are improved by open channel work. There are a number of streams, such as the Arkansas, included above, which by this method do not yield navigation more than a part of the year.

Greatest of all the tributaries in navigable length is the Red River, the last to enter the Mississippi from the west. It is also one of those which have offered the most complicated problems. In the early days this river was obstructed by a great "raft" of timber, brought down by its current, into which it had been hurled by caving banks. This raft formerly extended as far down as Natchitoches, or even lower, and its removal by Henry M. Shreve about 1838 marked the beginning of river work in that department. Shreve cut a way through with his snagboat at an expense of $300,000, against ten times that sum estimated to be the cost, and extended navigation a long distance up the stream. From that time until near the opening of the Civil War the government kept the stream fairly clear, the Red River bottoms were partially leveed, and the Red River trade was the richest in all Western steamboating. Before the actual outbreak of the war, however, the work was suspended, and in the course of the next few years the raft again accumulated, being now above Shreveport, and entirely covering the surface of the river for

thirty miles or more, augmenting this length annually. In 1872, when federal attention was again turned to the stream, the raft extended for 32 miles, and as an obstacle to navigation effectually seconded the efforts of 200 steamboat hulks which were sunk in the channels and on the bars of the river.

The existence of this raft in early days caused the floods of the Red to seek other outlets than through the lower course of the river, and many bayous were created through the bottom lands into which the current frequently shifted, so that the channel was unstable to a degree not met with on any other water. Many of these bayous had been closed by levee lines; but the war period saw these broken, and it became the task of the river improvers to confine the lower reach of the river to its own channel—chiefly by closing Tones's bayou, near Shreveport—and to open the upper reaches by cutting out the raft. The closing of the bayou proved a long and costly work, but was at length accomplished. The raft was first cut through and then entirely removed, though timber still accumulates rapidly. Opening

of the raft gave high-water steamboat channels to Fulton, Arkansas, 508.6 miles from the mouth, and snagging cleared the high-water way an additional 170 miles to the mouth of the Kiamichi River in the Indian Territory.

The removal of the raft had the effect of causing the bottom to cut 10 feet at its head and 3 feet at Shreveport, establishing a more even slope and draining many thousands of acres of wonderfully fertile alluvial lands above it, adding to the wealth and healthfulness of that country.

On the Lower Red River the falls at Alexandria have been the subject of considerable work, deepening the low-water channel from 2.5 to 5.5 feet. Dredging, revetting, chute-closing, and snagging along the river have gradually improved the stream so that now, when there is one foot on the gauge at Shreveport there is three-foot navigation to Fulton, and at standard low water there is 3 feet to Montgomery, 162.5 miles; 2.5 feet to Shreveport, 320.5 miles; and 2 feet to Fulton, 508.6 miles from the mouth of the stream. One hundred and fifty miles of new

levee and one hundred of enlargement, fifteen per cent of it by the federal authorities, have been built, to the further improvement and steadiness of the channel.

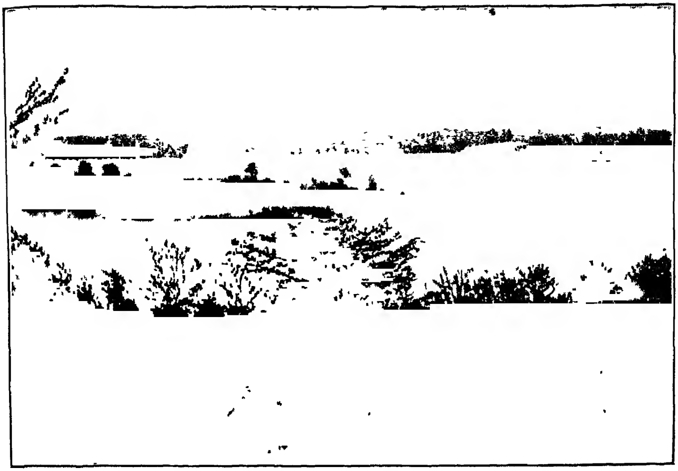
The chief affluent of the Red is the Washita and Black,—but one river,—which is navigable under varying circumstances at moderate and high stages to Camden, Arkansas, 360 miles. A new project, recently adopted, calls for slack-water in this stream, and appropriations have been made for the first two of nine locks and movable dams, which, when the channel work has been correlated to them, will give six and a half feet of water to Camden at all stages.

Next in order of magnitude of the tributaries come the Tennessee and Cumberland, already described, and then the Arkansas and White, which enter the Mississippi through a common mouth some distance below Memphis. The Arkansas is a stream in some ways resembling the Missouri, having a scanty rainfall on a wide basin, and but a small run-off. The low water of its upper reach in summer is abstracted for irrigation purposes, leaving its bed almost dry; so that

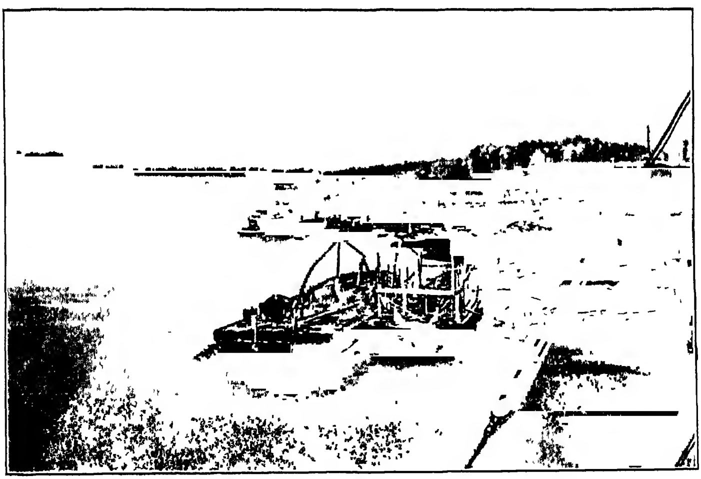
though Congress has adopted a plan calling for navigation as far as Wichita, 770 miles, there seems no prospect that it will be obtained. Theoretically, the head of steamboat navigation is now at Fort Gibson, on the Grand River, about two miles from the Arkansas; and in recent years barges, and even steamboats, have ascended in good seasons to Muskogee. A proposition has been made, and has found favor in Oklahoma, to dig a canal from the capital city to the Arkansas; and if that is done, some means will probably be found for extending navigation that far up the river. But navigation in this shallow stream is at the best uncertain. In spite of much work done on a project adopted years ago, to secure six feet of water as far up as Little Rock, no such channel has as yet come into being; and the best that has been obtained in recent years at moderately low water, which is the best stage which prevails when the demands of commerce are the heaviest, have been to give extremely shoal navigation to Little Rock and a regular three-foot channel to Pine Bluff. In 1901 there was no navigation above Shoal Creek, 88 miles below Fort Smith,

and only 12 inches for a long distance below there The Arkansas costs large sums for snagging, and eventually, if open channels are obtained, must be extensively revetted and contracted.

The White River, its chief affluent, has quite another history. From its small shed in the Ozarks it draws a steady flow, which enables navigation on it to be extended by slack-water, so that the head of navigation is now put at Forsythe, Missouri, 505 miles up the stream. This is, however only for moderate stages. There is now at low water 3 feet to Jacksonport, 264 miles; 16 inches from there to Batesville, 37 miles; and a slack-water project was undertaken a few years ago to give 5 feet to Buffalo Shoals, 89 miles. There being no outlet for this five-foot channel, and no means for using it, nor any contemplated except an occasional high water tendered free by a beneficent Providence, and no towns at the headwater, and no freight to carry, and no boats on the river, Congress, after spending some $684,109.78 upon the project, has abandoned it One of the dams has been given over, free of charge, to a private lighting company at Bates-



THE YAZOO CUT. ARTIFICIAL CHANNEL FOR THE YAZOO INTO CENTENNIAL LAKE



VICKSBURG CANAL. ARTIFICIAL MOUTH OF THE YAZOO FROM CENTENNIAL LAKE TO THE MISSISSIPPI

ville, to be used to develop electric power, and now permission is given to another individual to build a third dam, in its proper place, for the purpose of securing the power there.

One of the most important tributary systems of the Mississippi, on account of its rich country and its easy channels, is the Yazoo, which, according to the estimates of the Chief of Engineers, offers 800 miles of channel. Of this, 240 is in the Yazoo itself, a good three-foot water at all stages; a large proportion is available at low, and the rest at very moderate stages. This is in a rich cotton country; the waters have been improved at little cost (chiefly by snagging and dredging and some contraction), and the whole system has been and is kept continually and profitably in use.

A different story is to be told of the Wabash and White rivers of Indiana. These streams, which were formerly much used in connection with the canal system from the Ohio to Toledo, have been improved at a total cost of more than one million dollars to the federal government, including a dam and lock at the Grand Rapids of

the Wabash. In spite of this, however, there has been no means adopted of providing low-water depths in the Ohio and the lower reach of the Wabash, and there remains to-day a few miles of three-foot channel above Grand Rapids, and a few miles of twenty-inch water below, with better depths at better stages, and no connection with the outside world when the Ohio is below seven feet. The White River is now to be electrically harnessed.

On none of these systems so far described, except the Yazoo, is there anything like completion obtained, or enough done to indicate what will be the ability of the engineers to maintain the depths for which they are striving. On the upper waters of the Ohio, where slack-water is general and of long standing, we find rivers completely organized and well operated, though frequently with distressing lack of system.

The Ohio itself is formed by two slack-watered streams. The Monongahela was dammed and pooled, with locks, three quarters of a century ago, for the purpose of getting coal out of the mountains. From those pools has always come

the greater part of the trade which goes down the Ohio to the Mississippi. Those dams and locks have recently been acquired by the federal government. They carry five feet of water to the West Virginia line. Above that the government some time ago constructed two locks and dams to carry vessels to Morgantown, and now six dams have been added, which provide coal-boat water as far up as Fairmount.

The Kanawhas, the Big Sandy, the Kentucky, and the Green and Barren have all been similarly treated, and as far as their internal reaches are concerned are in good working order, with five or six feet of water in all sections. At their mouths, however, they are blocked by the unimproved Ohio, and will not attain their proper usefulness for many years. The tributaries of the Upper Mississippi have without exception been improved by the open channel method. The Fox and the Chippewa have been abandoned, and most of the Minnesota has been given up, only a short stretch, patronized by excursion boats, having been dredged and contracted. The St. Croix has been kept open for the use of lumbermen, and

on account of the multitude of logs drifted down it no other navigation is possible.

One cannot long study the story of these tributary waters without being struck with the lack of any comprehensive or orderly plan for their development and utilization. This has partly grown, as I have said in an earlier chapter, out of the early necessity by which each was hastily developed as a necessary means of communication for the early settlers. But that day has long gone by, and the illogical methods persist, with the result that the obstacles to through commerce are being perpetuated, until they will reach a stage at which their removal will be enormously costly. To understand this we have only to study the following list of locks mounted or in adopted projects on the slack-water streams, not considering the open channel work which, we must believe, will some day be brought into relation to them.

River.	Number.	Lock Chambers.			
		Length (available).	Width.	Built.	Depth over lower sills.
Monongahela .	1*	158	50	1841	5.6–7
* These are double locks, one of first 4 beside each of next 4.	2*	215	56	1848	
	1*	225	56	1886	
	1*	277	56	1883	
	1	165.5	50	1856	3.4
	2	159	50	1853, 1886	4–5.5
	1	160	50	1879	7.15
	1	161.7	50	1882	6
	7	177	56	1905	7
Allegheny . .	1	286.2	55	1897	7
	2	289.6	56	1903	7
Great Kanawha	1	271	50	1887	8.67
	1	272	50	1882	7
	2	274	50	1880	6.5
	6	313	55	1886–1898	6.08–8.25
Little Kanawha	4	125	22	1867	3.5
	1	126	26	1891	4
Muskingum . .	8	160	36	1836–1891	4.5–5.5
	1	366	56	1890	3
	2	158	35.5	1836	5.4
Big Sandy . .	2	158	55	1904	6–7.3
	1	158	52	1896	6
Green	3	138	36	1835	1–6.8
	2	145	36	1899	5.1
Barren . . .	1	140	36	1835	4.5
Rough . . .	1	123	27	1896	5.2
Kentucky . .	5	145	38	1844	6
	1	147	52	1891	6
	2	148	52	1897–1900	6
Ohio River . .	14 (to be more)	600	110	building	
" (Louisville)	2	350	80	1873	4.8
Tennessee . .	1	340	80	1897	7
	11	285	60	1889	5
Cumberland .	22	280	52	building	6.5
Wabash . . .	1	214	52		3.5
White, Ark. .	10	147	35	building	5
Washita . . .	9	350	45	building	6.5
Illinois . . .	4	350	75		7
Mississippi . .	5	325	78.5		
Osage	1	220	42	building	
Lakes-Gulf proposed . . .		600	80		

The absurdity of such a lack of system is too apparent on the face of it to need pointing out. Nevertheless, there are some features even in this medley that are especially aggravating. Thus, on the Tennessee, the single lock at Colbert's Shoals is made of ample size, while those at the Muscle Shoals, through which all steamers must pass to reach Chattanooga, and which when the plan is complete will be on a waterway of even depth, are twenty feet narrower and fifty-five feet shorter. No matter to what extent the channel is improved, therefore, the smallest of these locks limits the size of steamers ascending to Chattanooga, and the extra cost of the larger lock must be justified by the local traffic between it and the Muscle Shoals. Nothing can justify the engineers for shutting the Chattanooga reach against vessels of equal size with the lower section. On the Monongahela the presence of larger locks at headwaters than lower down is only an evidence of intention to enlarge the lower locks later, the old ones having been built by a company; a similar excuse may avail on the Great Kanawha. But no explanation is at hand for the action of

the engineers in making locks 286 by 56 serve the Allegheny, while on a similar stream of equal depth, the Kanawha, they find 313 by 55 a suitable size. On the Green and Barren they seem to have adopted a size about 145 by 36, but on the Rough, a tributary, with the same depth, they have cut this to 123 by 27. The Cumberland is given locks 5 feet shorter than those of the Tennessee, and eight feet narrower, thus shutting out from this neighboring traffic boats made to accommodate the Chattanooga trade. The Wabash lock conforms to nothing else, the isolated White River locks are in a class with those of the Green and Barren, the Kentucky sets another standard. In fact, there is a wide variety, but so arranged that only a narrow boat of little length has choice of the streams for traffic.

The day has passed when the United States can afford work of this character, or can afford, either, to allow these streams to be blocked with costly masonry which does not develop their trade.

There also remains to be solved the problem of the ownership of the power in these navigable

streams. To whom shall it belong? And who shall pay for the making of it? In order to approach the question with some information, Congress has required from the Corps of Engineers a report on the water-power developed by the dams between St. Paul and Minneapolis, to determine how much is available and at what periods, how it can be developed without injuring navigation, and how it should be disposed of. But long before the question had been brought up there, it had been met and passed lightly by on the Tennessee, the Cumberland, the White, and other streams. On the Tennessee at Muscle Shoals and at the other steep places, there are large possibilities for water-power at points where it is much needed. The common plan of operations in such a case has been for Congress to permit some party chartered by the state to erect a dam across the stream, on condition that if it interferes with navigation Congress may erect a lock adjoining it and control the flow of water for the benefit of shipping. On the Tennessee, however, where the steepest shoals are passed by canal and lock, an investigation is under way to determine

to what extent slack-water may be developed in the river itself, and whether the dam-builders can properly be made to carry out each project. Farther up, at Scott Point, or Hale's Bar, where there was open channel navigation, Congress has permitted a private corporation to dam the river, on condition that it provide a suitable lock, the Corps of Engineers providing plans and oversight. This will much improve the situation at and above Chattanooga, at slight cost to the government. It would seem that in all cases in which a water-power privilege was owned by private persons, and there was already a fall which obstructed navigation, the power owners might very properly be allowed to build their dams and the federal engineers to build the locks, after the manner anciently followed. On the other hand, where Congress has created a water-power by slack-watering a stream to better an ancient open channel, as in the Upper White River, there should be compensation to the government for the power used, which should go toward paying for the dam. No such compensation is provided for in the act which gives away the power on the White at

Batesville, it being provided that the private persons interested may take possession of this government dam, construct races and other parts needed, and draw the water for power, giving the nation so much as is needed to operate the lock, and being restricted only to the point at which their withdrawal of water would interfere with navigation. The project of slack-watering on the Upper White has been withdrawn, because there is at present no reason for its fulfillment. When it is extended down to Jacksonport and the work again undertaken, this question must be met squarely, and should be settled with a decision either to allow the dams to be built by and at the expense of companies which are to operate the power, or to have the power development go hand in hand with the dam construction and the revenue from the sale go toward the reimbursement for the outlay.

On the Cumberland, again, this question must be met, and on the upper waters of that river Congress has solved it by allowing a navigation company to establish lock and pool navigation and use the power at the dams. On the Missis-

sippi above Minneapolis every dam privilege is granted without recompense, although the owners get the full benefit of the steady flow from the expensive reservoirs created by the government. They are only required to leave room for a future lock. On the Ohio the question has not yet been publicly raised. The movable dams are not tight, three or four inches being left between wickets to allow for bending and getting out of alignment. But by the use of needles at these gaps it is possible to make the dams almost tight, and to reserve a great deal of the regular summer flow to be passed through turbines. This power would be intermittent, but at times exceedingly valuable.

Taken all together, the water-powers upon our navigable streams are very large, and there will be many more streams added to the navigable list when the demand for electrical power has so increased that more rivers can be profitably slack-watered. The two things should never be separated in the minds of the engineers who are planning the work.

So much, then, for the minor streams flowing into the great trunk lines of the Mississippi. Like

the greater streams, they can never come to their best working out until the navigable waters of America are considered as a whole by some government organization, and are developed, not at the annually changing whim of Congress, but by the steadily growing and continually unified plan of an understanding commission or commissioner. It may take us some years yet to come to it, or the temporary commission which President Roosevelt has appointed may bring us sooner to it. But the years that elapse before the accomplishment need not be wasted, and indeed may be made very profitable if they be used for the study of the best means of making the best use of those rivers we have and of those we hope to get.

CHAPTER XII

THE UTILIZATION OF THE CHANNELS

THE purpose of this volume is not to discuss in any detail the new plans for the conservation of water under which the future developments of the Mississippi channels will be carried out, and which I hope to take up in a second work, nor to describe the methods by which the channels have been and will be best turned to commercial account. Nevertheless, it does not appear suitable to close it without a short sketch of the rise and decline of river traffic, and an indication of some of the causes of success and of failure therein.

In the earliest days river traffic was carried on by drifting boats, built of timber or rough lumber, most of which went down to New Orleans from the interior loaded with native produce, and were broken up and sold for wood at New Orleans. In addition, there were "keel-boats," in model not unlike the standard barges seen to-

day on European rivers, which returned upstream under the impetus of sail, oar, and cordeling rope, and occasionally of side-wheels turned by horse-power. As early as 1802 the steamboat began to be discussed on the river, and in that year one was built for a Mr. McKeever, who had secured a privilege from the Intendant at New Orleans. His boat was destroyed before being finished, however, and aside from a few experimental models on Fitch's plan on the Ohio, no steam vessel floated on the river until the building of the first Fulton steamboat in 1811, the New Orleans. The Fulton-Livingston monopoly secured from the Louisiana legislature a monopoly of steam traffic on the lower river, but a young pioneer, Henry M. Shreve, having designed a boat more able than theirs, attacked them in court and defeated them.

Thereafter, under the stimulating enthusiasm of Shreve, who made many inventions and gave them without patent to his countrymen, the Mississippi River steamboat advanced more rapidly toward perfection than any other similar craft in the world; so that in twenty years there were

several hundred high-pressure steamboats plying the stream, carrying fabulous cargoes at high freight rates. They were all built after practically the same model, designed by Shreve, and were like the antique packets to be seen on the river to-day. Their engines were for the time magnificent, using even at that epoch steam at 160 pounds pressure. But the boats themselves had many faults. Their immense radial wheels weakened their hulls by continual pounding upon the water. Their hulls and light decks, built flimsily to save weight, were liable to destruction by fire, and burned so rapidly when the overheated boilers started combustion as to cause many terrible disasters. The light wooden hulls were easily penetrated by snags, wrecking the boats. And the channel, from which eventually the Shreve snagboat cleared most of these obstructions, was so irregular and so unreliable that the boats frequently ran aground and were either lost or delayed.

Nevertheless, some of these vessels were extremely fast, making twenty miles an hour at an early epoch; and so long as slave labor continued

they were able to do business with fair economy. Several new developments, however, came to the river simultaneously. The war ended slave labor and destroyed the prosperity of the South. It also made for many years an entire end to river transportation, caused the burning or sinking of hundreds of steamboats, and the impoverishment of all those who depended upon steam navigation for a livelihood. At the same time a railroad for the first time paralleled the river and another cut across it, joining the Western fields directly to the East.

During the continuance of the war it was necessary for the North to carry to the seaboard ports and for distribution to the army the grain of the new West. The exporting of this grain and of meat stores was essential in order to maintain foreign credit and to provide the expenses of the war. Every energy was turned toward the creation and improvement of transcontinental lines; and inventive genius, fascinated by this problem of national safety and by the rich rewards from success, turned toward the improvement of the locomotive and to all parts of the railway service.

At the same time the Eastern harbors were being improved, deep steam vessels were supplanting the old wooden sailing ships, and the South was stagnating. Naturally, when the war closed, the river was unable to recover. There was no longer a fighting chance for it. It had at its mouth the impoverished city of New Orleans, and a channel through which only old clippers drawing at best sixteen feet of water could pass. In its export rates and facilities it could not compare with any of the Eastern ports. Its terminals had no facilities for handling freight. Slave labor was abolished, but no substitute for it except the free darky had been devised. The steamboat of Shreve, with no new improvements of value, continued to be the river type. It could compete with the railway of its own time; but in a channel uncertain and dreaded it could not compete with the quicker, safer, and in the end not more expensive railway of the post-bellum days.

As a result, though the river traffic increased rapidly after the war until about 1871, and produced such famous vessels as the R. E. Lee and the Natchez, it became evident that it was only

a last burst before the death of the old-style methods. The combination passenger and freight boat, with its many handicaps, could no longer hold its own. An endeavor was made to substitute towed freight-barges carrying grain from St. Louis to New Orleans, and after the opening of the Mississippi mouth by Eads and the erection of elevators at New Orleans this traffic considerably increased. St. Louis arrived at a freight movement by water of more than a million tons a year, not including her local transfer service.

Still there remained several handicaps on the service, some of which were and some were not perceived by those interested. In order that river traffic may compete with rail, it must have the same facilities for cheap transfer, for quick handling, and for safety, as the railway has. On the Mississippi there was not from end to end any facility for loading and unloading package freight except the brawny negroes, who still "toted" by hand even the heaviest packages. The boats were still the old sort, with no possibility of receiving or delivering cargo except by hand or trucks. Even the barges which carried

grain down from St. Louis were roofed over, so that while grain might be piped into their holds, the return cargo must be put aboard by hand. There were no proper railway terminals at the levees, and freight which went to and from the river even at important terminal cities paid as high as $1 or even $2 a ton for local teaming charges.

There were no harbors along the stream, and the packets employed the ancient method of picking up and delivering freight at every plantation, much as if the trains from New Orleans to Chicago should stop for cotton bales at every plantation they passed.

Successful traffic on the river requires, just as it does on rail, a complete separation of passenger and freight service. Passengers must be handled on swift, comfortable, through boats. Freight requires more time, and a different type of vessel. Nowhere on the river were these two classes of boats provided, except in the case of the St. Louis grain and the Pittsburg coal barges. So St. Louis, handicapped by its own inefficiency, saw its water traffic drop back to a third of a

million tons a year, all of which is local freight for small towns below or for plantations. Only a single movement of freight remained prosperous on the river, that of coal upon the Ohio. The movement of this in immense fleets—sometimes 60,000 tons at a time—on the high water, downstream, is one of the largest and cheapest freight movements in the world, being carried out at a cost less than the cheapest ocean freightage. The empty barges are pushed upstream for reloading, often with small cargoes of return freight, and the transfers are accomplished more quickly and economically than by rail. Yet even this is still done in the old-fashioned way; and there is no doubt that the present charges would be cut in half by study and the use of modern methods.

It is commonly said now that the railways killed the through traffic of the Mississippi. This is far from the truth. The traffic became moribund from stagnation, by the failure of American men to apply to it the same inventive energy and the same free use of capital which they applied to the railway service. But it was finally

wounded almost fatally by the uncertainty of the channels and the inefficiency of the terminal service; two things which were tolerable when there was no other route, but which became intolerable as soon as the railway did away with them. At any time within the last twenty years the Mississippi might have been profitably revived by the organization of a competent corporation large enough to systematize and develop the trade, wise enough to provide modern machinery in all departments, and rich enough to weather the first months of proving to the shipping interests their sufficiency.

Now, however, we have arrived at a new epoch. The turning of traffic toward the Gulf has forced the railways into new efficiency. The opening of Panama will more than double our trade in that direction. The present certainty of our channels, deeper than the best in Europe, makes traffic easy. There only remains the proper transshipping terminal apparatus and the proper boats to be provided, and these channels of the Mississippi will become the greatest carriers and the greatest arteries of our internal system.

pleted, and the Missouri once more fairly in control, there should be almost an equal traffic going from east to west and west to east, by Erie Canal barges or by river barges, from the eastern seaboard, through the canal, through the Pittsburg way, down and up the Ohio, around by Cairo to St. Louis, and so by the Missouri for distribution from and collection in the great depots at Kansas City, Omaha, and Sioux City.

Then the Mississippi will have come into its own; and then all America, feeling the increase of prosperity with this cheap and efficient internal circulation, will benefit from the belated and irregular expenditures we have made upon the Remaking of the Mississippi.

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